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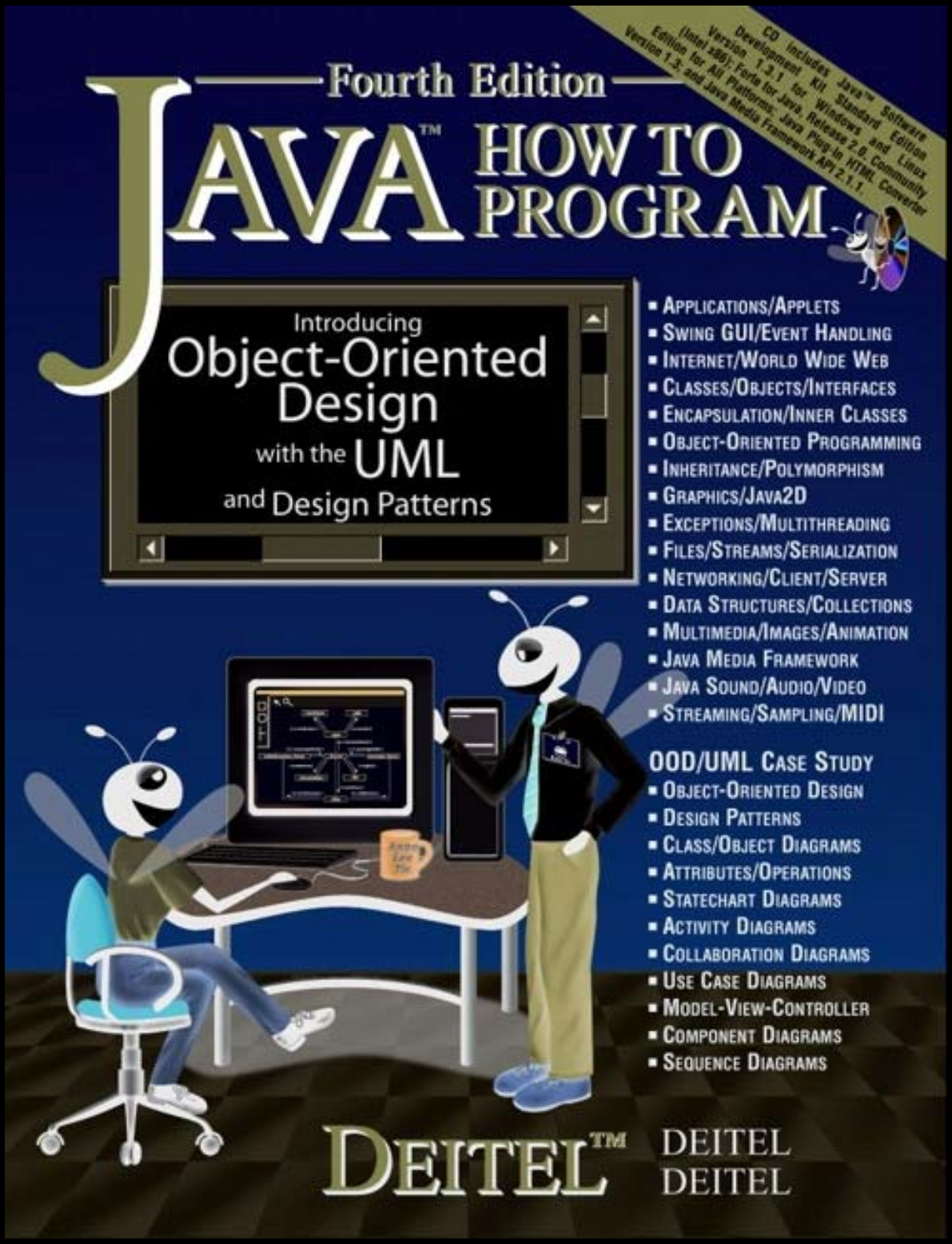

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Introduction to Computers, the Internet and the Web

Objectives

- To understand basic computer science concepts.
- To become familiar with different types of programming languages.
- To introduce the Java development environment.
- To understand Java's role in developing distributed client/server applications for the Internet and Web.
- To introduce object-oriented design with the UML and design patterns.
- To preview the remaining chapters of the book.

Our life is frittered away by detail … Simplify, simplify.
Henry Thoreau

High thoughts must have high language.
Aristophanes

The chief merit of language is clearness.
Galen

My object all sublime
I shall achieve in time.
W. S. Gilbert

He had a wonderful talent for packing thought close, and rendering it portable.
Thomas Babington Macaulay

Egad, I think the interpreter is the hardest to be understood of the two!
Richard Brinsley Sheridan

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Outline

1.1 Introduction
1.2 What Is a Computer?
1.3 Computer Organization
1.4 Evolution of Operating Systems
1.5 Personal, Distributed and Client/Server Computing
1.6 Machine Languages, Assembly Languages and High-Level Languages
1.7 History of C++
1.8 History of Java
1.9 Java Class Libraries
1.10 Other High-Level Languages
1.11 Structured Programming
1.12 The Internet and the World Wide Web
1.13 Basics of a Typical Java Environment
1.14 General Notes about Java and This Book
1.15 Thinking About Objects: Introduction to Object Technology and the Unified Modeling Language
1.16 Discovering Design Patterns: Introduction
1.17 Tour of the Book
1.18 (Optional) A Tour of the Case Study on Object-Oriented Design with the UML
1.19 (Optional) A Tour of the "Discovering Design Patterns" Sections

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

1.1 Introduction

Welcome to Java! We have worked hard to create what we hope will be an informative, entertaining and challenging learning experience for you. Java is a powerful computer programming language that is fun to use for novices and appropriate for experienced programmers building substantial information systems. *Java How to Program: Fourth Edition* is designed to be an effective learning tool for each of these audiences.

How can one book appeal to both groups? The answer is that the common core of the book emphasizes achieving program *clarity* through the proven techniques of *structured programming* and *object-oriented programming*. Nonprogrammers will learn programming the right way from the beginning. We have attempted to write in a clear and straightforward manner. The book is abundantly illustrated. Perhaps most importantly, the book presents hundreds of working Java programs and shows the outputs produced when those programs are run on a computer. We teach all Java features in the context of complete working Java programs. We call this the *live-code™ approach.* These examples are available from three locations—they are on the CD that accompanies this book, they may be

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downloaded from our Web site **www.deitel.com** and they are available on our interactive CD product, the *Java 2 Multimedia Cyber Classroom: Fourth Edition*. The Cyber Classroom's features and ordering information appear at the back of this book. The Cyber Classroom also contains answers to approximately half of the solved exercises in this book, including short answers, small programs and many full projects. If you purchased *The Complete Java 2 Training Course: Fourth Edition*, you already have the Cyber Classroom.

The early chapters introduce the fundamentals of computers, computer programming and the Java computer programming language. Novices who have taken our courses tell us that the material in those chapters presents a solid foundation for the deeper treatment of Java in the later chapters. Experienced programmers tend to read the early chapters quickly and find that the treatment of Java in the later chapters is rigorous and challenging.

Many experienced programmers have told us that they appreciate our structured programming treatment. Often, they have been programming in structured languages like C or Pascal, but they were never formally introduced to structured programming, so they are not writing the best possible code in these languages. As they review structured programming in the chapters "Control Structures: Part 1" and "Control Structures: Part 2," they are able to improve their C and Pascal programming styles as well. So whether you are a novice or an experienced programmer, there is much here to inform, entertain and challenge you.

Most people are familiar with the exciting tasks computers perform. Using this textbook, you will learn how to command computers to perform those tasks. It is *software* (i.e., the instructions you write to command computers to perform *actions* and make *decisions*) that controls computers (often referred to as *hardware*), and Java is one of today's most popular software-development languages. Java was developed by Sun Microsystems and an implementation of it is available free over the Internet from the Sun Web site

```
java.sun.com/j2se
```

This book is based on the *Java 2 Platform, Standard Edition*, which describes the Java language, libraries and tools. Other vendors can implement *Java development kits* based on the *Java 2 Platform*. Sun provides an implementation of the *Java 2 Platform, Standard Edition* called the *Java 2 Software Development Kit, Standard Edition (J2SDK)* that includes the minimum set of tools you need to write software in Java. At the time of this publication, the most recent version was J2SDK 1.3.1. You can download future updates to the J2SDK from the Sun Web site **java.sun.com/j2se**.

Computer use is increasing in almost every field of endeavor. In an era of steadily rising costs, computing costs have been decreasing dramatically due to rapid developments in both hardware and software technology. Computers that might have filled large rooms and cost millions of dollars two decades ago can now be inscribed on the surfaces of silicon chips smaller than a fingernail, costing perhaps a few dollars each. Ironically, silicon is one of the most abundant materials on earth—it is an ingredient in common sand. Silicon-chip technology has made computing so economical that hundreds of millions of general-purpose computers are in use worldwide helping people in business, industry, government, and in their personal lives. The number of computers worldwide easily could double in the next few years.

This book will challenge you for several reasons. For many years, students learned C or Pascal as their first programming language. They probably learned the programming methodology called *structured programming*. You will learn both structured programming and the exciting newer methodology, *object-oriented programming*. Why do we teach both? We

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believe that object orientation is the key programming methodology of the future. You will build and work with many *objects* in this course. However, you will discover that the internal structure of those objects is built with structured programming techniques. Also, the logic of manipulating objects is occasionally best expressed with structured programming.

Another reason we present both methodologies is the continuing migration from C-based systems (built primarily with structured programming techniques) to C++ and Java-based systems (built primarily with object-oriented programming techniques). There is a huge amount of so-called "legacy C code" in place, because C has been in use for over three decades. Once people learn C++ or Java, they find these languages to be more powerful than C. These people often choose to move their programming projects to C++ or Java. They begin converting their legacy systems and begin employing the object-oriented programming capabilities of C++ or Java to realize the full benefits of these languages. Often, the choice between C++ and Java is made based on the simplicity of Java compared to C++.

Java has become the language of choice for implementing Internet-based and Intranet-based applications and software for devices that communicate over a network. Do not be surprised when your new stereo and other devices in your home will be networked together by Java technology! Also, do not be surprised when your wireless devices, like cell phones, pagers and personal digital assistants (PDAs) communicate over the so-called Wireless Internet via the kind of Java-based networking protocols that you will learn in this book and its companion *Advanced Java 2 Platform How to Program*.

Java is a particularly attractive first programming language. At the JavaOne™ trade show in June 2001, it was announced that Java is now a required part of the programming languages curriculum in 56% of US colleges and universities. Also, 87% of US colleges and universities offer Java courses. Java is attractive to high schools as well. In 2003, the College Board will standardize on Java for Advanced Placement computer science courses.

Java has evolved rapidly into the large-scale applications arena. Java is no longer a language used simply to make World Wide Web pages "come alive." Java has become the preferred language for meeting many organizations' programming needs.

For many years, languages like C and C++ appealed to universities because of their portability. Introductory courses could be offered in these languages on any hardware/operating system combination, as long as a C/C++ compiler was available. However, the programming world has become more complex and more demanding. Today, users want applications with graphical user interfaces (GUIs). They want applications that use multimedia capabilities such as graphics, images, animation, audio and video. They want applications that can run on the Internet and the World Wide Web and communicate with other applications. They want applications that can take advantage of the flexibility and performance improvements of multithreading (which enables programmers to specify that several activities should occur in parallel). They want applications with richer file processing than is provided by C or C++. They want applications that are not limited to the desktop or even to some local computer network, but can integrate Internet components and remote databases as well. They want applications that can be written quickly and correctly in a manner that takes advantage of prebuilt software components. They want easy access to a growing universe of reusable software components. Programmers want all these benefits in a truly portable manner, so that applications will run without modification on a variety of *platforms* (i.e., different types of computers running different operating systems). Java offers all these benefits to the programming community.

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Another reason Java is attractive for university courses is that it is fully object oriented. One reason that C++ use has grown so quickly is that it extends C programming into the arena of object orientation. For the huge community of C programmers, this has been a powerful advantage. C++ includes ANSI/ISO C and offers the ability to do object-oriented programming as well. (ANSI is the American National Standards Institute, and ISO is the International Standards Organization.) An enormous amount of C code has been written in industry over the last several decades. C++ is a superset of C, so many organizations find it to be an ideal next step. Programmers can take their C code, compile it (often with nominal changes) in a C++ compiler and continue writing C-like code while mastering the object paradigm. Then, the programmers can gradually migrate portions of the legacy C code into C++ as time permits. New systems can be entirely written in object-oriented C++. Such strategies have been appealing to many organizations. The downside is that, even after adopting this strategy, companies tend to continue producing C-like code for many years. This, of course, means that they do not realize the benefits of object-oriented programming quickly and could produce programs that are confusing and hard to maintain as a result of to their hybrid design. Many organizations would prefer to plunge 100% into object-oriented development, but the realities of mountains of legacy code and the temptation to take a C-programming approach often prevent this.

Java is a fully object-oriented language with strong support for proper software engineering techniques. It is difficult to write C-like, so-called procedural programs in Java. You must create and manipulate objects. Error processing is built into the language. Many of the complex details of C and C++ programming that prevent programmers from "looking at the big picture" are not included in Java. For universities, these features are powerfully appealing. Students will learn object-oriented programming from the start. They will simply think in an object-oriented manner.

Here, too, there is a trade-off. Organizations turning to Java for new applications development do not want to convert all their legacy code to Java. So Java allows for so-called *native code.* This means that existing C and C++ code can be integrated with Java code. Although this may seem a bit awkward (and it certainly can be), it presents a pragmatic solution to a problem most organizations face.

The fact that Java is free for download at the Sun Web site, **`java.sun.com/j2se`**, is appealing to universities facing tight budgets and lengthy budget planning cycles. Also, as bug fixes and new versions of Java are developed, these become available immediately over the Internet, so universities can keep their Java software current.

Can Java be taught in a first programming course—the intended audience for this book? We think so. Prior to writing this book, Deitel & Associates, Inc. instructors taught hundreds of Java courses to several thousand people at all levels of expertise, including many nonprogrammers. We found that nonprogrammers become productive faster with Java than with C or C++. They are anxious to experiment with Java's powerful features for graphics, graphical user interfaces, multimedia, animation, multithreading, networking and the like—and they are successful at building substantial Java programs even in their first courses.

For many years, the Pascal programming language was the preferred vehicle for use in introductory and intermediate programming courses. Many people said that C was too difficult a language for these courses. In 1992, we published the first edition of *C How to Program,* to encourage universities to try C instead of Pascal in these courses. We used the same pedagogic approach we had used in our university courses for a dozen years, but

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wrapped the concepts in C rather than Pascal. We found that students were able to handle C at about the same level as Pascal. However, there was one noticeable difference—students appreciated that they were learning a language (C) likely to be valuable to them in industry. Our industry clients appreciated the availability of C-literate graduates who could work immediately on substantial projects rather than first having to go through costly and time-consuming training programs.

The first edition of *C How to Program* included a 60-page introduction to C++ and object-oriented programming. We saw C++ coming on strong, but we felt it would be at least a few more years before the universities would be ready to teach C++ and object-oriented programming (OOP) in introductory courses.

During 1993, we saw a surge in interest in C++ and OOP among our industry clients, but we still did not sense that the universities were ready to switch to C++ and OOP en masse. So, in January 1994, we published the Second Edition of *C How to Program* with a 300-page section on C++ and OOP. In May 1994, we published the first edition of *C++ How to Program,* a 950-page book devoted to the premise that C++ and OOP were now ready for prime time in introductory university courses for many schools that wanted to be at the leading edge of programming-languages education.

In 1995, we were following the introduction of Java carefully. In November 1995, we attended an Internet conference in Boston. A representative from Sun Microsystems gave a presentation on Java that filled one of the large ballrooms at the Hynes Convention Center. As the presentation proceeded, it became clear to us that Java would play a significant part in the development of interactive, multimedia Web pages. We immediately saw a much greater potential for the language. We saw Java as the proper language for universities to teach first-year programming language students in this modern world of graphics, images, animation, audio, video, database, networking, multithreading and collaborative computing. At the time, we were busy writing the second edition of *C++ How to Program.* We discussed with our publisher, Prentice Hall, our vision of Java making a strong impact in the university curriculum. We all agreed to delay the second edition of *C++ How to Program* a bit so that we could get the first edition of *Java How to Program* (based on Java 1.0.2) to the market in time for fall 1996 courses.

As Java rapidly evolved to Java 1.1, we wrote *Java How to Program: Second Edition* in 1997, less than a year after the first edition reached bookstores. Hundreds of universities and corporate training programs worldwide used the second edition. To keep pace with the enhancements in Java, we published *Java How to Program: Third Edition* in 1999. The third edition was a major overhaul to upgrade the book to the *Java 2 Platform.*

Java continues to evolve rapidly, so we wrote this fourth edition of *Java How to Program*—our first book to reach a fourth edition—just five years after the first edition was published. This edition is based on the *Java 2 Platform, Standard Edition* (*J2SE*). Java has grown so rapidly over the last several years that it now has two other editions. The *Java 2 Platform, Enterprise Edition* (*J2EE*) is geared toward developing large-scale, distributed networking applications and Web-based applications. The *Java 2 Platform, Micro Edition* (*J2ME*) is geared toward development of applications for small devices (such as cell phones, pagers and personal digital assistants) and other memory-constrained applications. The number of topics to cover in Java has become far too large for one book. So, in parallel with *Java How to Program, Fourth Edition*, we are publishing *Advanced Java 2 Platform How to Program*, which emphasizes developing applications with J2EE and provides cov-

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erage of several high-end topics from the J2SE. In addition, this book also includes substantial materials on J2ME and wireless-application development.

So, there you have it! You are about to start on a challenging and rewarding path. As you proceed, please share your thoughts on Java and *Java How to Program: Fourth Edition* with us via e-mail at **deitel@deitel.com**. We will respond promptly.

Prentice Hall maintains **www.prenhall.com/deitel**—a Web site dedicated to our Prentice Hall publications, including textbooks, professional books, interactive multimedia CD-based *Cyber Classrooms*, *Complete Training Courses* (boxed products containing both a *Cyber Classroom* and the corresponding book), Web-based training, e-whitepapers, e-books and ancillary materials for all these products. For each of our books, the site contains companion Web sites that include frequently asked questions (FAQs), code downloads, errata, updates, additional text and examples, additional self-test questions and new developments in programming languages and object-oriented programming technologies. If you would like to learn more about the authors or Deitel & Associates, Inc. please visit **www.deitel.com**. Good luck!

1.2 What Is a Computer?

A *computer* is a device capable of performing computations and making logical decisions at speeds millions, even billions, of times faster than human beings can. For example, many of today's personal computers can perform hundreds of millions, even billions, of additions per second. A person operating a desk calculator might require decades to complete the same number of calculations a powerful personal computer can perform in one second. (*Points to ponder*: How would you know whether the person added the numbers correctly? How would you know whether the computer added the numbers correctly?) Today's fastest *supercomputers* can perform hundreds of billions of additions per second—about as many calculations as hundreds of thousands of people could perform in one year! And trillion-instruction-per-second computers are already functioning in research laboratories!

Computers process *data* under the control of sets of instructions called *computer programs.* These programs guide the computer through orderly sets of actions specified by people called *computer programmers.*

The various devices that comprise a computer system (such as the keyboard, screen, disks, memory and processing units) are referred to as *hardware.* The computer programs that run on a computer are referred to as *software.* Hardware costs have been declining dramatically in recent years, to the point that personal computers have become a commodity. Unfortunately, software-development costs have been rising steadily, as programmers develop ever more powerful and complex applications without being able to improve significantly the technology of software development. In this book, you will learn proven software-development methods that can reduce software-development costs—top-down stepwise refinement, functionalization and object-oriented programming. Object-oriented programming is widely believed to be the significant breakthrough that can greatly enhance programmer productivity.

1.3 Computer Organization

Regardless of differences in physical appearance, virtually every computer may be envisioned as being divided into six *logical units* or sections. These are as follows:

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1. *Input unit.* This is the "receiving" section of the computer. It obtains information (data and computer programs) from *input devices* and places this information at the disposal of the other units so that the information may be processed. Most information is entered into computers today through typewriter-like keyboards, "mouse" devices and disks. In the future, most information will be entered by speaking to computers, by electronically scanning images and by video recording.
2. *Output unit.* This is the "shipping" section of the computer. It takes information processed by the computer and places it on various *output devices* to make the information available for use outside the computer. Information output from computers is displayed on screens, printed on paper, played through audio speakers, magnetically recorded on disks and tapes or used to control other devices.
3. *Memory unit.* This is the rapid-access, relatively low-capacity "warehouse" section of the computer. It retains information that has been entered through the input unit so that the information may be made immediately available for processing when it is needed. The memory unit also retains information that has already been processed until that information can be placed on output devices by the output unit. The memory unit often is called either *memory, primary memory* or *random-access memory (RAM).*
4. *Arithmetic and logic unit (ALU).* This is the "manufacturing" section of the computer. It is responsible for performing calculations such as addition, subtraction, multiplication and division. It contains the decision mechanisms that allow the computer, for example, to compare two items from the memory unit to determine whether they are equal.
5. *Central processing unit (CPU).* This is the "administrative" section of the computer. It is the computer's coordinator and is responsible for supervising the operation of the other sections. The CPU tells the input unit when information should be read into the memory unit, tells the ALU when information from the memory unit should be utilized in calculations and tells the output unit when to send information from the memory unit to certain output devices.
6. *Secondary storage unit.* This is the long-term, high-capacity "warehousing" section of the computer. Programs or data not being used by the other units are normally placed on secondary storage devices (such as disks) until they are needed, possibly hours, days, months or even years later. Information in secondary storage takes longer to access than information in primary memory. The cost per unit of secondary storage is much less than the cost per unit of primary memory.

1.4 Evolution of Operating Systems

Early computers were capable of performing only one *job* or *task* at a time. This form of computer operation is often called single-user *batch processing*. The computer runs a single program at a time while processing data in groups or *batches.* In these early systems, users generally submitted their jobs to the computer center on decks of punched cards. Users often had to wait hours or even days before printouts were returned to their desks.

Software systems called *operating systems* were developed to help make it more convenient to use computers. Early operating systems managed the smooth transition between

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jobs. This minimized the time it took for computer operators to switch between jobs and hence increased the amount of work, or *throughput,* computers could process.

As computers became more powerful, it became evident that single-user batch processing rarely utilized the computer's resources efficiently. Instead, it was thought that many jobs or tasks could be made to *share* the resources of the computer to achieve better utilization. This is called *multiprogramming*. Multiprogramming involves the "simultaneous" operation of many jobs on the computer—the computer shares its resources among the jobs competing for its attention. With early multiprogramming operating systems, users still submitted jobs on decks of punched cards and waited hours or days for results.

In the 1960s, several groups in industry and the universities pioneered *timesharing* operating systems. Timesharing is a special case of multiprogramming in which users access the computer through *terminals*, typically devices with keyboards and screens. In a typical timesharing computer system, there may be dozens or even hundreds of users sharing the computer at once. The computer does not actually run all the users' jobs simultaneously. Rather, it runs a small portion of one user's job and moves on to service the next user. The computer does this so quickly that it might provide service to each user several times per second. Thus the users' programs *appear* to be running simultaneously. An advantage of timesharing is that the user receives almost immediate responses to requests rather than having to wait long periods for results, as with previous modes of computing. Also, if a particular user is currently idle, the computer can continue to service other users rather than wait for one user.

1.5 Personal, Distributed and Client/Server Computing

In 1977, Apple Computer popularized the phenomenon of *personal computing.* Initially, it was a hobbyist's dream. Computers became economical enough for people to buy them for their own personal use. In 1981, IBM, the world's largest computer vendor, introduced the IBM Personal Computer. Almost overnight, personal computing became legitimate in business, industry and government organizations.

But these computers were "stand-alone" units—people did their work on their own machines and transported disks back and forth to share information. Although early personal computers were not powerful enough to timeshare several users, these machines could be linked together in computer networks, sometimes over telephone lines and sometimes in *local area networks (LANs)* within an organization. This led to the phenomenon of *distributed computing,* in which an organization's computing, instead of being performed strictly at some central computer installation, is distributed over networks to the sites at which the real work of the organization is performed. Personal computers were powerful enough both to handle the computing requirements of individual users and to handle the basic communications tasks of passing information back and forth electronically.

Today's most powerful personal computers are as powerful as the million-dollar machines of just a decade ago. The most powerful desktop machines—called *workstations*—provide individual users with enormous capabilities. Information is shared easily across computer networks where some computers called *file servers* offer a common store of programs and data that may be used by *client* computers distributed throughout the network (hence the term *client/server computing*). C and C++ have become and remain the languages of choice for writing operating systems. They also remain popular for writing computer networking, distributed client/server and Internet and Web applications, although

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Java is now the dominant language in each of these areas. Many programmers have discovered that programming in Java helps them be more productive than programming in C or C++. Today's popular operating systems, such as UNIX, Linux, MacOS, Windows and Windows 2000, provide the kinds of capabilities discussed in this section.

1.6 Machine Languages, Assembly Languages and High-Level Languages

Programmers write instructions in various programming languages, some directly understandable by computers and others that require intermediate *translation* steps. Hundreds of computer languages are in use today. These may be divided into three general types:

1. Machine languages
2. Assembly languages
3. High-level languages

Any computer can directly understand only its own *machine language*. Machine language is the "natural language" of a particular computer. It is defined by the hardware design of that computer. Machine languages generally consist of strings of numbers (ultimately reduced to 1s and 0s) that instruct computers to perform their most elementary operations one at a time. Machine languages are *machine dependent* (i.e., a particular machine language can be used on only one type of computer). Machine languages are cumbersome for humans, as can be seen by the following section of a machine-language program that adds overtime pay to base pay and stores the result in gross pay.

```
+1300042774
+1400593419
+1200274027
```

As computers became more popular, it became apparent that machine-language programming was simply too slow and tedious for most programmers. Instead of using the strings of numbers that computers could directly understand, programmers began using English-like abbreviations to represent the elementary operations of computers. These English-like abbreviations formed the basis of *assembly languages. Translator programs* called *assemblers* were developed to convert assembly-language programs to machine language at computer speeds. The following section of an assembly-language program also adds overtime pay to base pay and stores the result in gross pay, but somewhat more clearly than its machine-language equivalent.

```
LOAD   BASEPAY
ADD    OVERPAY
STORE  GROSSPAY
```

Although such code is clearer to humans, it is incomprehensible to computers until translated to machine language.

Computer usage increased rapidly with the advent of assembly languages, but programming in these still required many instructions to accomplish even the simplest tasks. To speed the programming process, *high-level languages* were developed in which single statements could be written to accomplish substantial tasks. The translator programs that convert high-level language programs into machine language are called *compilers*. High-

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level languages allow programmers to write instructions that look almost like everyday English and contain commonly used mathematical notations. A payroll program written in a high-level language might contain a statement such as

```
grossPay = basePay + overTimePay
```

Obviously, high-level languages are much more desirable from the programmer's standpoint than either machine languages or assembly languages. C, C++ and Java are among the most powerful and most widely used high-level programming languages.

The process of compiling a high-level language program into machine language can take a considerable amount of computer time. *Interpreter* programs were developed to execute high-level language programs directly without the need for compiling those programs into machine language. Although compiled programs execute much faster than interpreted programs, interpreters are popular in program-development environments in which programs are recompiled frequently as new features are added and errors are corrected. Once a program is developed, a compiled version can be produced to run most efficiently. As we study Java, you will see that interpreters have played an especially important part in helping Java achieve its goal of portability across a great variety of platforms.

1.7 History of C++

C++ evolved from C, which evolved from two previous languages, BCPL and B. BCPL was developed in 1967 by Martin Richards as a language for writing operating-systems software and compilers. Ken Thompson modeled many features in his language B after their counterparts in BCPL and used B to create early versions of the UNIX operating system at Bell Laboratories in 1970 on a Digital Equipment Corporation PDP-7 computer. Both BCPL and B were "typeless" languages—every data item occupied one "word" in memory. For example, it was the programmer's responsibility to treat a data item as a whole number or a real number.

The C language was evolved from B by Dennis Ritchie at Bell Laboratories and was originally implemented on a DEC PDP-11 computer in 1972. C uses many important concepts of BCPL and B while adding data typing and other features. C initially became widely known as the development language of the UNIX operating system. Today, virtually all new major operating systems are written in C or C++. Over the past two decades, C has become available for most computers. C is hardware independent. With careful design, it is possible to write C programs that are *portable* to most computers.

By the late 1970s, C had evolved into what is now referred to as "traditional C," or "Kernighan and Ritchie C." The publication by Prentice Hall in 1978 of Kernighan and Ritchie's book, *The C Programming Language,* brought wide attention to the language. This publication became one of the most successful computer science books ever.

The widespread use of C with various types of computers (sometimes called *hardware platforms*) led to many variations. These were similar, but often incompatible. This was a serious problem for programmers who needed to write portable programs that would run on several platforms. It became clear that a standard version of C was needed. In 1983, the X3J11 technical committee was created under the American National Standards Committee on Computers and Information Processing (X3) to "provide an unambiguous and machine-independent definition of the language." In 1989, the standard was approved. ANSI cooperated with the International Standards Organization (ISO) to standardize C

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worldwide; the joint standard document was published in 1990 and is referred to as ANSI/ISO 9899: 1990. The second edition of Kernighan and Ritchie,[1] published in 1988, reflects this version called ANSI C, a version of the language still used worldwide (Ke88).

C++, an extension of C, was developed by Bjarne Stroustrup in the early 1980s at Bell Laboratories. C++ provides a number of features that "spruce up" the C language, but more importantly, it provides capabilities for *object-oriented programming*. C++ was also standardized by the ANSI and ISO committees.

There is a revolution brewing in the software community. Building software quickly, correctly and economically remains an elusive goal, and this at a time when demands for new and more powerful software are soaring. *Objects* are essentially reusable software *components* that model items in the real world. Software developers are discovering that using a modular, object-oriented design and implementation approach can make software-development groups much more productive than is possible with previous popular programming techniques such as structured programming. Object-oriented programs are often easier to understand, correct and modify.

Many other object-oriented languages have been developed, including Smalltalk, developed at Xerox's Palo Alto Research Center (PARC). Smalltalk is a pure object-oriented language—literally everything is an object. C++ is a hybrid language—it is possible to program in either a C-like style, an object-oriented style or both.

1.8 History of Java

Perhaps the microprocessor revolution's most important contribution to date is that it made possible the development of personal computers, which now number in the hundreds of millions worldwide. Personal computers have had a profound impact on people and the way organizations conduct and manage their business.

Many people believe that the next major area in which microprocessors will have a profound impact is in intelligent consumer-electronic devices. Recognizing this, Sun Microsystems funded an internal corporate research project code-named Green in 1991. The project resulted in the development of a C- and C++-based language that its creator, James Gosling, called Oak after an oak tree outside his window at Sun. It was later discovered that there already was a computer language called Oak. When a group of Sun people visited a local coffee place, the name Java was suggested, and it stuck.

The Green project ran into some difficulties. The marketplace for intelligent consumer-electronic devices was not developing as quickly as Sun had anticipated. Worse yet, a major contract for which Sun competed was awarded to another company. So the project was in danger of being canceled. By sheer good fortune, the World Wide Web exploded in popularity in 1993, and Sun people saw the immediate potential of using Java to create Web pages with so-called *dynamic content*. This breathed new life into the project.

Sun formally announced Java at a major conference in May 1995. Ordinarily, an event like this would not have generated much attention. However, Java generated immediate interest in the business community because of the phenomenal interest in the World Wide Web. Java is now used to create Web pages with dynamic and interactive content, to develop large-scale enterprise applications, to enhance the functionality of World Wide

1. Kernighan, B. W., and D. M. Ritchie, *The C Programming Language* (Second Edition), Englewood Cliffs, NJ: Prentice Hall, 1988.

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Web servers (the computers that provide the content we see in our Web browsers), to provide applications for consumer devices (such as cell phones, pagers and personal digital assistants) and for many other purposes.

1.9 Java Class Libraries

Java programs consist of pieces called *classes*. Classes consist of pieces called *methods* that perform tasks and return information when they complete their tasks. You can program each piece you may need to form a Java program. However, most Java programmers take advantage of rich collections of existing classes in *Java class libraries*. The class libraries are also known as the *Java APIs (Application Programming Interfaces)*. Thus, there are really two pieces to learning the Java "world." The first is learning the Java language itself so that you can program your own classes; the second is learning how to use the classes in the extensive Java class libraries. Throughout the book, we discuss many library classes. Class libraries are provided primarily by compiler vendors, but many class libraries are supplied by independent software vendors (ISVs). Also, many class libraries are available from the Internet and World Wide Web as *freeware* or *shareware*. You can download freeware products and use them for free—subject to any restrictions specified by the copyright owner. You also can download shareware products for free, so you can try the software. Shareware products often are free of charge for personal use. However, for shareware products that you use regularly or use for commercial purposes, you are expected to pay a fee designated by the copyright owner.

Many freeware and shareware products are also *open source*. The source code for open-source products is freely available on the Internet, which enables you to learn from the source code, validate that the code serves its stated purpose and even modify the code. Often, open-source products require that you publish any enhancements you make so the open-source community can continue to evolve those products. One example of a popular open-source product is the Linux operating system.

Software Engineering Observation 1.1

Use a building-block approach to creating programs. Avoid reinventing the wheel. Use existing pieces—this is called software reuse *and it is central to object-oriented programming.*

[*Note*: We will include many of these *Software Engineering Observations* throughout the text to explain concepts that affect and improve the overall architecture and quality of software systems, and particularly, of large software systems. We will also highlight *Good Programming Practices* (practices that can help you write programs that are clearer, more understandable, more maintainable and easier to test and debug), *Common Programming Errors* (problems to watch out for so you do not make these same errors in your programs), *Performance Tips* (techniques that will help you write programs that run faster and use less memory), *Portability Tips* (techniques that will help you write programs that can run, with little or no modifications, on a variety of computers; these tips also include general observations about how Java achieves its high degree of portability), *Testing and Debugging Tips* (techniques that will help you remove bugs from your programs and, more important, techniques that will help you write bug-free programs to begin with) and *Look and Feel Observations* (techniques that will help you design the "look" and "feel" of your graphical user interfaces for appearance and ease of use). Many of these techniques and practices are only guidelines; you will, no doubt, develop your own preferred programming style.]

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Software Engineering Observation 1.2

When programming in Java, you will typically use the following building blocks: Classes from class libraries, classes and methods you create yourself and classes and methods other people create and make available to you.

The advantage of creating your own classes and methods is that you know exactly how they work and you can examine the Java code. The disadvantage is the time-consuming and complex effort that goes into designing and developing new classes and methods.

Performance Tip 1.1

Using Java API classes and methods instead of writing your own versions can improve program performance, because these classes and methods are carefully written to perform efficiently. This technique also improves the prototyping speed of program development (i.e., the time it takes to develop a new program and get its first version running).

Portability Tip 1.1

Using classes and methods from the Java API instead of writing your own versions improves program portability, because these classes and methods are included in every Java implementation (assuming the same version number).

Software Engineering Observation 1.3

Extensive class libraries of reusable software components are available over the Internet and the Web. Many of these libraries provide source code and are available at no charge.

1.10 Other High-Level Languages

Hundreds of high-level languages have been developed, but only a few have achieved broad acceptance. *Fortran* (FORmula TRANslator) was developed by IBM Corporation between 1954 and 1957 to be used for scientific and engineering applications that require complex mathematical computations. Fortran is still widely used.

COBOL (COmmon Business Oriented Language) was developed in 1959 by a group of computer manufacturers and government and industrial computer users. COBOL is used primarily for commercial applications that require precise and efficient manipulation of large amounts of data. Today, about half of all business software is still programmed in COBOL. Approximately one million people are actively writing COBOL programs.

Pascal was designed at about the same time as C. It was created by Professor Nicklaus Wirth and was intended for academic use. We discuss Pascal further in the next section.

Basic was developed in 1965 at Dartmouth College as a simple language to help novices become comfortable with programming. *Bill Gates* implemented Basic on several early personal computers. Today, *Microsoft*—the company Bill Gates created—is the world's leading software-development organization.

1.11 Structured Programming

During the 1960s, many large software-development efforts encountered severe difficulties. Software schedules were typically late, costs greatly exceeded budgets and the finished products were unreliable. People began to realize that software development was a far more complex activity than they had imagined. Research activity in the 1960s resulted

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in the evolution of *structured programming*—a disciplined approach to writing programs that are clearer than unstructured programs, easier to test and debug and easier to modify. Chapters 4 and 5 discuss the principles of structured programming.

One of the more tangible results of this research was the development of the Pascal programming language by Nicklaus Wirth in 1971. Pascal, named after the seventeenth-century mathematician and philosopher Blaise Pascal, was designed for teaching structured programming in academic environments and rapidly became the preferred programming language in most universities. Unfortunately, the language lacks many features needed to make it useful in commercial, industrial and government applications, so it has not been widely accepted in these environments.

The Ada programming language was developed under the sponsorship of the United States Department of Defense (DOD) during the 1970s and early 1980s. Hundreds of separate languages were being used to produce DOD's massive command-and-control software systems. DOD wanted a single language that would fill most of its needs. Pascal was chosen as a base, but the final Ada language is quite different from Pascal. The language was named after Lady Ada Lovelace, daughter of the poet Lord Byron. Lady Lovelace is credited with writing the world's first computer program in the early 1800s (for the Analytical Engine mechanical computing device designed by Charles Babbage). One important capability of Ada is called *multitasking*, which allows programmers to specify that many activities are to occur in parallel. The native capabilities of other widely used high-level languages we have discussed—including C and C++—generally allow the programmer to write programs that perform only one activity at a time. Java, through a technique we will explain called *multithreading*, also enables programmers to write programs with parallel activities. [*Note*: Most operating systems provide libraries specific to individual platforms (sometimes called *platform-dependent libraries*) that enable high-level languages like C and C++ to specify that many activities are to occur in parallel in a program.]

1.12 The Internet and the World Wide Web

The *Internet* was developed more than three decades ago with funding supplied by the Department of Defense. Originally designed to connect the main computer systems of about a dozen universities and research organizations, the Internet today is accessible by hundreds of millions of computers worldwide.

With the introduction of the *World Wide Web*—which allows computer users to locate and view multimedia-based documents on almost any subject—the Internet has exploded into one of the world's premier communication mechanisms.

The Internet and the World Wide Web will surely be listed among the most important and profound creations of humankind. In the past, most computer applications ran on computers that were not connected to one another. Today's applications can be written to communicate among the world's hundreds of millions of computers. The Internet mixes computing and communications technologies. It makes our work easier. It makes information instantly and conveniently accessible worldwide. It makes it possible for individuals and local small businesses to get worldwide exposure. It is changing the nature of the way business is done. People can search for the best prices on virtually any product or service. Special-interest communities can stay in touch with one another. Researchers can be made instantly aware of the latest breakthroughs worldwide.

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Java How to Program: Fourth Edition presents programming techniques that allow Java applications to use the Internet and World Wide Web to interact with other applications. These capabilities, and the capabilities discussed in our companion book *Advanced Java 2 Platform How to Program*, allow Java programmers to develop the kind of enterprise-level distributed applications that are used in industry today. Java applications can be written to execute on any computer platform, yielding major savings in systems development time and cost for corporations. If you have been hearing a great deal about the Internet and World Wide Web lately, and if you are interested in developing applications to run over the Internet and the Web, learning Java may be the key to challenging and rewarding career opportunities for you.

1.13 Basics of a Typical Java Environment

Java systems generally consist of several parts: An environment, the language, the Java Applications Programming Interface (API) and various class libraries. The following discussion explains a typical Java program development environment, as shown in Fig. 1.1.

Java programs normally go through five phases to be executed (Fig. 1.1). These are: *edit, compile, load, verify* and *execute.* We discuss these concepts in the context of the *Java 2 Software Development Kit (J2SDK)* that is included on the CD that accompanies this book. *Carefully follow the installation instructions for the J2SDK provided on the CD to ensure that you set up your computer properly to compile and execute Java programs.* [*Note*: If you are not using UNIX/Linux, Windows 95/98/ME or Windows NT/2000, refer to the manuals for your system's Java environment or ask your instructor how to accomplish these tasks in your environment (which will probably be similar to the environment in Fig. 1.1).]

Phase 1 consists of editing a file. This is accomplished with an *editor program* (normally known as an *editor*). The programmer types a Java program, using the editor, and makes corrections, if necessary. When the programmer specifies that the file in the editor should be saved, the program is stored on a secondary storage device, such as a disk. Java program file names end with the ***.java*** *extension*. Two editors widely used on UNIX/Linux systems are **vi** and **emacs**. On Windows 95/98/ME and Windows NT/2000, simple edit programs like the DOS Edit command and the Windows Notepad will suffice. Java integrated development environments (IDEs), such as Forté for Java Community Edition, NetBeans, Borland's JBuilder, Symantec's Visual Cafe and IBM's VisualAge have built-in editors that are integrated into the programming environment. We assume the reader knows how to edit a file.

[Note that Forté for Java Community Edition is written in Java and is free for non-commercial use. It is included on the CD accompanying this book. Sun updates this software approximately twice a year. Newer versions can be downloaded from

www.sun.com/forte/ffj

Forté for Java Community Edition executes on most major platforms. This book is written for any generic Java 2 development environment. It is not dependent on Forté for Java Community Edition. Our example programs should operate properly with most Java integrated development environments.]

In Phase 2 (discussed again in Chapters 2 and 3), the programmer gives the command ***javac*** to *compile* the program. The Java compiler translates the Java program into *byte-*

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codes—the language understood by the Java interpreter. To compile a program called **`Welcome.java`**, type

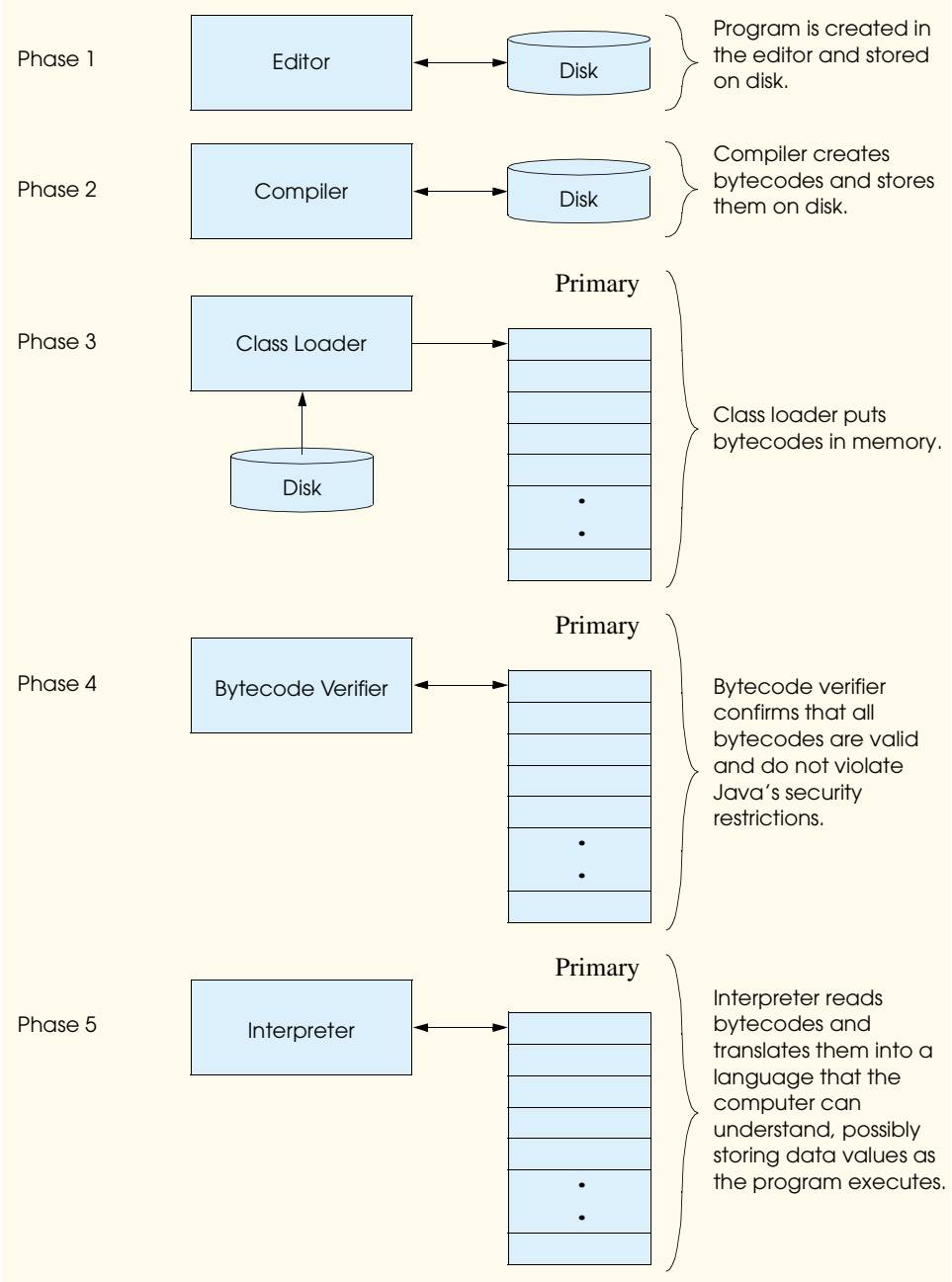

Fig. 1.1 Typical Java environment.

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```
javac Welcome.java
```

at the command window of your system (i.e., the *MS-DOS prompt* in Windows, the *Command Prompt* in Windows NT/2000 or the *shell prompt* in UNIX/Linux). If the program compiles correctly, the compiler produces a file called **Welcome.class**. This is the file containing the bytecodes that will be interpreted during the execution phase.

Phase 3 is called *loading*. The program must first be placed in memory before it can be executed. This is done by the *class loader,* which takes the **.class** file (or files) containing the bytecodes and transfers it to memory. The **.class** file can be loaded from a disk on your system or over a network (such as your local university or company network or even the Internet). There are two types of programs for which the class loader loads **.class** files—*applications* and *applets*. An application is a program (such as a word-processor program, a spreadsheet program, a drawing program or an e-mail program) that normally is stored and executed from the user's local computer. An applet is a small program that normally is stored on a remote computer that users connect to via a World Wide Web browser. Applets are loaded from a remote computer into the browser, executed in the browser and discarded when execution completes. To execute an applet again, the user must point a browser at the appropriate location on the World Wide Web and reload the program into the browser.

Applications are loaded into memory and executed by using the *Java interpreter* via the command ***java***. When executing a Java application called **Welcome**, the command

```
java Welcome
```

invokes the interpreter for the **Welcome** application and causes the class loader to load information used in the **Welcome** program. [*Note*: Many Java programmers refer to the interpreter as the *Java Virtual Machine* or the *JVM*.]

The class loader also executes when a World Wide Web browser such as *Netscape Navigator* or *Microsoft Internet Explorer* loads a Java applet. Browsers are used to view documents on the World Wide Web called *Hypertext Markup Language* (*HTML*) documents. HTML describes the format of a document in a manner that is understood by the browser application (we introduce HTML in Section 3.4; for a detailed treatment of HTML and other Internet programming technologies, please see our text *Internet and World Wide Web How to Program, Second Edition*). An HTML document may refer to a Java applet. When the browser sees an applet referenced in an HTML document, the browser launches the Java class loader to load the applet (normally from the location where the HTML document is stored). Each browser that supports Java has a built-in Java interpreter. After the applet loads, the browser's Java interpreter executes the applet. Applets can also execute from the command line, using the ***appletviewer*** *command* provided with the J2SDK—the set of tools including the compiler (**javac**), interpreter (**java**), **appletviewer** and other tools used by Java programmers. Like Netscape Navigator and Microsoft Internet Explorer, the **appletviewer** requires an HTML document to invoke an applet. For example, if the **Welcome.html** file refers to the **Welcome** applet, the **appletviewer** command is used as follows:

```
appletviewer Welcome.html
```

This causes the class loader to load the information used in the **Welcome** applet. The **appletviewer** is a minimal browser—it knows only how to interpret references to applets and ignores all other HTML in a document.

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Before the Java interpreter built into a browser or the **`appletviewer`** executes the bytecodes in an applet, the bytecodes are verified by the *bytecode verifier* in Phase 4. This ensures that the bytecodes for classes that are loaded from the Internet (referred to as *downloaded classes*) are valid and that they do not violate Java's security restrictions. Java enforces strong security, because Java programs arriving over the network should not be able to cause damage to your files and your system (as computer viruses might). Note that bytecode verification also occurs in applications that download classes from a network.

Finally, in Phase 5, the computer, under the control of its CPU, interprets the program one bytecode at a time, thus performing the actions specified by the program.

Programs might not work on the first try. Each of the preceding phases can fail because of various errors that we will discuss in this text. For example, an executing program might attempt to divide by zero (an illegal operation in Java just as it is in arithmetic). This would cause the Java program to print an error message. The programmer would return to the edit phase, make the necessary corrections and proceed through the remaining phases again to determine that the corrections work properly.

Common Programming Error 1.1

Errors like division-by-zero errors occur as a program runs, so these errors are called runtime errors *or* execution-time errors. Fatal runtime errors *cause programs to terminate immediately without having successfully performed their jobs.* Nonfatal runtime errors *allow programs to run to completion, often producing incorrect results.*

Most programs in Java input or output data. When we say that a program prints a result, we normally mean that the program displays results on the computer screen. Data may be output to other devices, such as disks and hardcopy printers.

1.14 General Notes about Java and This Book

Java is a powerful language. Experienced programmers sometimes take pride in being able to create some weird, contorted, convoluted usage of a language. This is a poor programming practice. It makes programs more difficult to read, more likely to behave strangely, more difficult to test and debug and more difficult to adapt to changing requirements. This book is also geared for novice programmers, so we stress *clarity*. The following is our first "good programming practice."

Good Programming Practice 1.1

Write your Java programs in a simple and straightforward manner. This is sometimes referred to as KIS ("keep it simple"). Do not "stretch" the language by trying bizarre usages.

You have heard that Java is a portable language and that programs written in Java can run on many different computers. For programming in general, *portability is an elusive goal*. For example, the ANSI C standard document[2] contains a lengthy list of portability issues, and complete books have been written that discuss portability.[3,4]

2. ANSI, *American National Standard for Information Systems–Programming Language C (ANSI Document ANSI/ISO 9899: 1990),* New York, NY: American National Standards Institute, 1990.
3. Jaeschke, R., *Portability and the C Language,* Indianapolis, IN: Hayden Books, 1989.
4. Rabinowitz, H., and C. Schaap, *Portable C,* Englewood Cliffs, NJ: Prentice Hall, 1990.

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Portability Tip 1.2

Although it is easier to write portable programs in Java than in other programming languages, there are differences among compilers, interpreters and computers that can make portability difficult to achieve. Simply writing programs in Java does not guarantee portability. The programmer will occasionally need to deal with compiler and computer variations.

Testing and Debugging Tip 1.1

Always test your Java programs on all systems on which you intend to run those programs, to ensure that your Java programs will work correctly for their intended audience.

We have done a careful walkthrough of Sun's Java documentation and audited our presentation against it for completeness and accuracy. However, Java is a rich language, and there are some subtleties in the language and some topics we have not covered. If you need additional technical details on Java, we suggest that you read the most current Java documentation available over the Internet at **`java.sun.com`**. Our book contains an extensive bibliography of books and papers on the Java language in particular and on object-oriented programming in general. A Web-based version of the Java API documentation can be found at **`java.sun.com/j2se/1.3/docs/api/index.html`**. Also, you can download this documentation to your own computer from **`java.sun.com/j2se/1.3/docs.html`**.

Good Programming Practice 1.2

Read the documentation for the version of Java you are using. Refer to this documentation frequently to be sure you are aware of the rich collection of Java features and that you are using these features correctly.

Good Programming Practice 1.3

Your computer and compiler are good teachers. If, after carefully reading your Java documentation manual, you are not sure how a feature of Java works, experiment and see what happens. Study each error or warning message you get when you compile your programs, and correct the programs to eliminate these messages.

Good Programming Practice 1.4

The Java 2 Software Development Kit comes with the Java source code. Many programmers read the actual source code of the Java API classes to determine how those classes work and to learn additional programming techniques. If the Java API documentation is not clear on a particular topic, try studying the source code of the class.

In this book, we explain how Java works in its current implementations. Perhaps the most striking problem with the early versions of Java is that Java programs execute interpretively on the client's machine. Interpreters execute slowly compared to fully compiled machine code.

Performance Tip 1.2

Interpreters have an advantage over compilers for the Java world, namely that an interpreted program can begin execution immediately as soon as it is downloaded to the client's machine, whereas a source program to be compiled must first suffer a potentially long delay as the program is compiled before it can be executed.

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Portability Tip 1.3

Although only Java interpreters were available to execute bytecodes at the client's site on early Java systems, compilers that translate Java bytecodes (or in some cases the Java source code) into the native machine code of the client's machine have been written for most popular platforms. These compiled programs perform comparably to compiled C or C++ code. However, there are not bytecode compilers for every Java platform, so Java programs will not perform at the same level on all platforms.

Applets present some more interesting issues. Remember, an applet could be coming from virtually any *Web server* in the world. So the applet will have to be able to run on any possible Java platform.

Portability Tip 1.4

Short, fast-executing Java applets can certainly still be interpreted. But what about more substantial, compute-intensive applets? Here, the user might be willing to suffer the compilation delay to get better execution performance. For some especially performance-intensive applets, the user might have no choice; interpreted code would run too slowly for the applet to perform properly, so the applet would have to be compiled.

Portability Tip 1.5

An intermediate step between interpreters and compilers is a just-in-time (JIT) compiler that, as the interpreter runs, produces compiled code for the programs and executes the programs in machine language rather than reinterpreting them. JIT compilers do not produce machine language that is as efficient as that from a full compiler.

Portability Tip 1.6

For the latest information on high-speed Java program translation, you might want to read about Sun's HotSpot™ compiler, so visit **`java.sun.com/products/hotspot`***. The HotSpot compiler is a standard component of the Java 2 Software Development Kit.*

The Java compiler, **`javac`**, is not a traditional compiler in that it does not convert a Java program from source code into native machine code for a particular computer platform. Instead, the Java compiler translates source code into bytecodes. Bytecodes are the language of the Java Virtual Machine—a program that simulates the operation of a computer and executes its own machine language (i.e., Java bytecodes). The Java Virtual Machine is implemented in the J2SDK as the **`java`** interpreter, which translates the bytecodes into native machine language for the local computer platform.

Software Engineering Observation 1.4

For organizations wanting to do heavy-duty information systems development, Integrated Development Environments (IDEs) are available from many major software suppliers, including Sun Microsystems. The IDEs provide many tools for supporting the software-development process, such as editors for writing and editing programs, debuggers for locating logic errors in programs and many other features.

Software Engineering Observation 1.5

Sun Microsystems, Inc.'s powerful Java IDE—Forté for Java, Community Edition—is available on the CD that accompanies this book and can be downloaded from **`www.sun.com/forte/ffj`***.*

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1.15 Thinking About Objects: Introduction to Object Technology and the Unified Modeling Language

Now we begin our early introduction to object orientation. We will see that object orientation is a natural way of thinking about the world and a natural way of writing computer programs.

In the bodies of each of the first seven chapters, we concentrate on the "conventional" methodology of structured programming, because the objects we will build will be composed in part of structured-program pieces. However, we end each chapter with a "Thinking About Objects" section in which we present a carefully paced introduction to object orientation. Our goal in these "Thinking About Objects" sections is to help you develop an object-oriented way of thinking, so that you immediately can use the object-oriented programming techniques that we present starting in Chapter 8. The "Thinking About Objects" sections also introduce you to the *Unified Modeling Language (UML)*. The UML is a graphical language that allows people who build systems (e.g., software architects, systems engineers, programmers and so on) to represent their object-oriented designs, using a common notation.

In this section, we introduce basic concepts (i.e., "object think") and terminology (i.e., "object speak"). Chapters 2–13, 15 and 22 and Appendices G–I include optional "Thinking About Objects" sections that present a substantial case study that applies the techniques of *object-oriented design (OOD)*. The optional sections at the ends of Chapters 2 through 7 analyze a typical problem statement that requires a system to be built, determine the objects required to implement that system, determine the attributes the objects will have, determine the behaviors these objects will exhibit and specify how the objects will interact with one another to meet the system requirements. All this occurs *before* you learn to write object-oriented Java programs! The optional sections at the ends of Chapters 8–13 and 15 modify and enhance the design presented in Chapters 2–7. Chapter 22 presents how to display our multimedia-rich design on the screen. The optional "Thinking About Objects" sections in each chapter apply the concepts discussed in that chapter to the case study. In Appendices G, H and I, we present a complete Java implementation of the object-oriented system we design in the earlier chapters.

This case study will help prepare you for the kinds of substantial projects you are likely to encounter in industry. If you are a student and your instructor does not plan to include this case study in your course, you may want to cover it on your own time. We believe it will be well worth your time to walk through this large and challenging project, because the material presented in the case-study sections reinforces the material covered in the corresponding chapters. You will experience a solid introduction to object-oriented design with the UML. Also, you will sharpen your code-reading skills by touring a carefully written and well-documented 3,594-line Java program that completely solves the problem presented in the case study.

We begin our introduction to object orientation with some key terminology. Everywhere you look in the real world you see them—*objects*: People, animals, plants, cars, planes, buildings, computers and so on. Humans think in terms of objects. We possess the marvelous ability of *abstraction*, which enables us to view screen images such as people, planes, trees and mountains as objects, rather than as individual dots of color (called *pixels*—for "picture elements"). We can, if we wish, think in terms of beaches rather than grains of sand, forests rather than trees and houses rather than bricks.

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We might be inclined to divide objects into two categories—animate objects and inanimate objects. Animate objects are "alive" in some sense; they move around and do things. Inanimate objects, on the other hand, seem not to do much at all. They do not move on their own. All these objects, however, do have some things in common. They all have *attributes* like size, shape, color, and weight, and they all exhibit *behaviors* (e.g., a ball rolls, bounces, inflates and deflates; a baby cries, sleeps, crawls, walks and blinks; a car accelerates, brakes and turns; a towel absorbs water).

Humans learn about objects by studying their attributes and observing their behaviors. Different objects can have similar attributes and can exhibit similar behaviors. Comparisons can be made, for example, between babies and adults and between humans and chimpanzees. Cars, trucks, little red wagons and roller skates have much in common.

Object-oriented design models real-world objects. It takes advantage of *class* relationships, where objects of a certain class—such as a class of vehicles—have the same characteristics. It takes advantage of *inheritance* relationships, and even *multiple-inheritance*[5] relationships, where newly created classes of objects are derived by absorbing characteristics of existing classes and adding unique characteristics of their own. An object of class "convertible" certainly has the characteristics of the more general class "automobile," plus a convertible's roof goes up and down.

Object-oriented design provides a more natural and intuitive way to view the design process—namely, by *modeling* real-world objects, their attributes, their behavior. OOD also models communication between objects. Just as people send *messages* to one another (e.g., a sergeant commanding a soldier to stand at attention), objects also communicate via messages.

OOD *encapsulates* data (attributes) and functions (behavior) into *objects;* the data and functions of an object are intimately tied together. Objects have the property of *information hiding.* This means that, although objects may know how to communicate with one another across well-defined *interfaces,* objects normally are not allowed to know how other objects are implemented—implementation details are hidden within the objects themselves. Surely, it is possible to drive a car effectively without knowing the details of how engines, transmissions and exhaust systems work internally. We will see why information hiding is so crucial to good software engineering.

Languages such as Java are *object-oriented*—programming in such a language is called *object-oriented programming* (*OOP*) and allows designers to implement the object-oriented design as a working system. Languages such as C, on the other hand, are *procedural programming languages,* so programming tends to be *action-oriented.* In C, the unit of programming is the *function.* In Java, the unit of programming is the *class* from which objects are eventually *instantiated* (a fancy term for "created"). Java classes contain *methods* (that implement class behaviors) and attributes (that implement class data).

C programmers concentrate on writing functions. Groups of actions that perform some common task are formed into functions, and functions are grouped to form programs. Data are certainly important in C, but the view is that data exist primarily in support of the actions that functions perform. The *verbs* in a system specification help the C programmer determine the set of functions needed to implement that system.

Java programmers concentrate on creating their own *user-defined types* called *classes* and *components.* Each class contains data and the set of functions that manipulate that data.

5. We will learn later that although Java—unlike C++—does not support multiple inheritance, it does offer most of the key benefits of this technology by supporting multiple interfaces per class.

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The data components of a Java class are called *attributes.* The function components of a Java class are called *methods*. Just as an instance of a built-in type such as **`int`** is called a *variable,* an instance of a user-defined type (i.e., a class) is called an *object.* The programmer uses built-in types as the "building blocks" for constructing user-defined types. The focus in Java is on classes (out of which we make objects) rather than on functions. The *nouns* in a system specification help the Java programmer determine the set of classes from which objects will be created that will work together to implement the system.

Classes are to objects as blueprints are to houses. We can build many houses from one blueprint, and we can instantiate many objects from one class. Classes can also have relationships with other classes. For example, in an object-oriented design of a bank, the "bank-teller" class needs to relate to the "customer" class. These relationships are called *associations*.

We will see that, when software is packaged as classes, these classes can be *reused* in future software systems. Groups of related classes are often packaged as reusable *components*. Just as real-estate brokers tell their clients that the three most important factors affecting the price of real estate are "location, location and location," many people in the software community believe that the three most important factors affecting the future of software development are "reuse, reuse and reuse."

Indeed, with object technology, we can build much of the software we will need by combining "standardized, interchangeable parts" called classes. This book teaches you how to "craft valuable classes" for reuse. Each new class you create will have the potential to become a valuable software asset that you and other programmers can use to speed and enhance the quality of future software-development efforts—an exciting possibility.

Introduction to Object-Oriented Analysis and Design (OOAD)

You soon will be writing programs in Java. How will you create the code for your programs? If you are like many beginning programmers, you will simply turn on your computer and start typing. This approach may work for small projects, but what would you do if you were asked to create a software system to control the automated teller machines for a major bank? Such a project is too large and complex for you to sit down and simply start typing.

To create the best solutions, you should follow a detailed process for obtaining an *analysis* of your project's *requirements* and developing a *design* for satisfying those requirements. Ideally, you would go through this process and have its results reviewed and approved by your superiors before writing any code for your project. If this process involves analyzing and designing your system from an object-oriented point of view, we call it an *object-oriented analysis and design (OOAD) process.* Experienced programmers know that, no matter how simple a problem appears, time spent on analysis and design can save innumerable hours that might be lost from abandoning an ill-planned system-development approach part of the way through its implementation.

OOAD is the generic term for the ideas behind the process we employ to analyze a problem and develop an approach for solving it. Small problems like the ones discussed in these first few chapters do not require an exhaustive process. It may be sufficient to write *pseudocode* before we *begin* writing code. (Pseudocode is an informal means of expressing program code. It is not actually a programming language, but we can use it as a kind of "outline" to guide us as we write our code. We introduce pseudocode in Chapter 4.)

Pseudocode can suffice for small problems, but as problems and the groups of people solving these problems increase in size, the methods of OOAD become more involved. Ide-

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ally, a group should agree on a strictly defined process for solving the problem and on a uniform way of communicating the results of that process to one another. Although many different OOAD processes exist, a single graphical language for communicating the results of any OOAD process has become widely used. This language is known as the *Unified Modeling Language (UML)*. The UML was developed in the mid-1990s under the initial direction of three software methodologists: Grady Booch, James Rumbaugh and Ivar Jacobson.

History of the UML

In the 1980s, increasing numbers of organizations began using OOP to program their applications, and a need developed for an established process with which to approach OOAD. Many methodologists—including Booch, Rumbaugh and Jacobson—individually produced and promoted separate processes to satisfy this need. Each of these processes had its own notation, or "language" (in the form of graphical diagrams), to convey the results of analysis and design.

By the early 1990s, different companies, and even different divisions within the same company, were using different processes and notations. Additionally, these companies wanted to use software tools that would support their particular processes. With so many processes, software vendors found it difficult to provide such tools. Clearly, a standard notation and standard processes were needed.

In 1994, James Rumbaugh joined Grady Booch at Rational Software Corporation, and the two began working to unify their popular processes. They were soon joined by Ivar Jacobson. In 1996, the group released early versions of the UML to the software engineering community and requested feedback. Around the same time, an organization known as the *Object Management Group™ (OMG™)* invited submissions for a common modeling language. The OMG is a not-for-profit organization that promotes the use of object-oriented technology by issuing guidelines and specifications for object-oriented technologies. Several corporations—among them HP, IBM, Microsoft, Oracle and Rational Software—had already recognized the need for a common modeling language. These companies formed the *UML Partners* in response to the OMG's request for proposals. This consortium developed the UML version 1.1 and submitted it to the OMG. The OMG accepted the proposal and, in 1997, assumed responsibility for the continuing maintenance and revision of the UML. In 2001, the OMG released the UML version 1.4 (the current version at the time this book was published) and is working on version 2.0 (scheduled tentatively for release in 2002).

What is the UML?

The Unified Modeling Language is now the most widely used graphical representation scheme for modeling object-oriented systems. It has indeed unified the various popular notational schemes. Those who design systems use the language (in the form of graphical diagrams) to model their systems.

An attractive feature of the UML is its flexibility. The UML is extendable and is independent of the many OOAD processes. UML modelers are free to develop systems by using various processes, but all developers can now express those systems with one standard set of notations.

The UML is a complex, feature-rich graphical language. In our "Thinking About Objects" sections, we present a concise, simplified subset of these features. We then use this subset to guide the reader through a first design experience with the UML intended for the

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novice object-oriented designer/programmer. For a more complete discussion of the UML, refer to the Object Management Group's Web site (**www.omg.org**) and to the official UML 1.4 specifications document (**www.omg.org/uml**). In addition, many UML books have been published: *UML Distilled: Second Edition*, by Martin Fowler (with Kendall Scott) (ISBN #020165783X) provides a detailed introduction to the UML, with many examples. *The Unified Modeling Language User Guide* (ISBN #0201571684), written by Booch, Rumbaugh and Jacobson, is the definitive tutorial to the UML. The reader looking for an interactive learning product might consider Grady Booch's *The Complete UML Training Course* (ISBN #0130870145).

Object-oriented technology is ubiquitous in the software industry, and the UML is rapidly becoming so. Our goal in these "Thinking About Objects" sections is to encourage you to think in an object-oriented manner as early, and as often, as possible. In the "Thinking About Objects" section at the end of Chapter 2, you will begin to apply object technology to implement a solution to a substantial problem. We hope that you will find this optional project to be an enjoyable and challenging introduction to object-oriented design with the UML and to object-oriented programming.

1.16 Discovering Design Patterns: Introduction

This section begins our treatment of design patterns, entitled "Discovering Design Patterns." Most of the examples provided in this book contain fewer than 150 lines of code. These examples do not require an extensive design process, because they use only a few classes and illustrate introductory programming concepts. However, some programs, such as our optional elevator-simulation case study, are more complex—they can require thousands of lines of code or even more, contain many interactions among objects and involve many user interactions. Larger systems, such as automated teller machines or air-traffic control systems, could contain millions of lines of code. Effective design is crucial to the proper construction of such complex systems.

Over the past decade, the software engineering industry has made significant progress in the field of *design patterns*—proven architectures for constructing flexible and maintainable object-oriented software.[6] Using design patterns can substantially reduce the complexity of the design process. Designing an ATM system will be a somewhat less formidable task if developers use design patterns. In addition, well-designed object-oriented software allows designers to reuse and integrate preexisting components in future systems. Design patterns benefit system developers by

- helping to construct reliable software using proven architectures and accumulated industry expertise
- promoting design reuse in future systems
- helping to identify common mistakes and pitfalls that occur when building systems
- helping to design systems independently of the language in which they will ultimately be implemented

6. Gamma, Erich, Richard Helm, Ralph Johnson, and John Vlissides. *Design Patterns; Elements of Reusable Object-Oriented Software*. (Massachusetts: Addison-Wesley, 1995).

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- establishing a common design vocabulary among developers
- shortening the design phase in a software-development process

The notion of using design patterns to construct software systems originated in the field of architecture. Architects use a set of established architectural design elements, such as arches and columns, when designing buildings. Designing with arches and columns is a proven strategy for constructing sound buildings—these elements may be viewed as architectural design patterns.

In software, design patterns are neither classes nor objects. Rather, designers use design patterns to construct sets of classes and objects. To use design patterns effectively, designers must familiarize themselves with the most popular and effective patterns used in the software-engineering industry. In this chapter, we discuss fundamental object-oriented design patterns and architectures, as well as their importance in constructing well-engineered software.

We present several design patterns in Java, but these design patterns can be implemented in any object-oriented language, such as C++ or Visual Basic. We describe several design patterns used by Sun Microsystems in the Java API. We use design patterns in many programs in this book, which we will identify throughout our discussion. These programs provide examples of using design patterns to construct reliable, robust object-oriented software.

History of Object-Oriented Design Patterns

During 1991–1994, Erich Gamma, Richard Helm, Ralph Johnson, and John Vlissides—collectively known as the "gang of four"—used their combined expertise to write the book *Design Patterns, Elements of Reusable Object-Oriented Software (Addison-Wesley: 1995)*. This book described 23 design patterns, each providing a solution to a common software design problem in industry. The book groups design patterns into three categories—*creational design patterns*, *structural design patterns* and *behavioral design patterns*. Creational design patterns describe techniques to instantiate objects (or groups of objects). Structural design patterns allow designers to organize classes and objects into larger structures. Behavioral design patterns assign responsibilities to objects.

The gang-of-four book showed that design patterns evolved naturally through years of industry experience. In his article *Seven Habits of Successful Pattern Writers*,[7] John Vlissides states that "the single most important activity in pattern writing is reflection." This statement implies that, to create patterns, developers must reflect on, and document, their successes (and mistakes). Developers use design patterns to capture and employ this collective industry experience, which ultimately helps them avoid making the same mistakes twice.

New design patterns are being created all the time and being introduced rapidly to designers worldwide via the Internet. The topic of design patterns has generally been viewed as advanced, but authors such as ourselves are working this material into introductory and intermediate-level textbooks to help make this important knowledge available to a much wider audience.

Our treatment of design patterns begins with this required section in Chapter 1 and continues with five optional "Discovering Design Patterns" sections at the ends of Chapters 9, 13, 15, 17 and 21. Each of these sections is placed at the end of the chapter that introduces

7. Vlissides, John. *Pattern Hatching; Design Patterns Applied*. (Massachusetts: Addison-Wesley, 1998).

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the necessary Java technologies. If you are a student and your instructor does not plan to include this material in your course, we encourage you to read this material on your own.

1.17 Tour of the Book

You are about to study one of today's most exciting and rapidly developing computer programming languages. Mastering Java will help you develop powerful business and personal computer-applications software. In this section, we take a tour of the many capabilities of Java you will study in *Java How to Program: Fourth Edition*.

Chapter 1—Introduction to Computers, the Internet and the Web—discusses what computers are, how they work and how they are programmed. The chapter gives a brief history of the development of programming languages from machine languages, to assembly languages, to high-level languages. The origin of the Java programming language is discussed. The chapter includes an introduction to a typical Java programming environment. The chapter also introduces object technology, the Unified Modeling Language and design patterns.

Chapter 2—Introduction to Java Applications—provides a lightweight introduction to programming *applications* in the Java programming language. The chapter introduces nonprogrammers to basic programming concepts and constructs. The programs in this chapter illustrate how to display (also called *outputting*) data on the screen to the user and how to obtain (also called *inputting*) data from the user at the keyboard. Some of the input and output is by performed using a *graphical user interface (GUI)* component called ***JOptionPane*** that provides predefined windows (called dialog boxes) for input and output. This allows a nonprogrammer to concentrate on fundamental programming concepts and constructs rather than on the more complex GUI event handling. Using **JOptionPane** here enables us to delay our introduction of GUI event handling to Chapter 6, "Methods." Chapter 2 also provides detailed treatments of *decision making* and *arithmetic operations*. After studying this chapter, the student will understand how to write simple, but complete, Java applications.

Chapter 3—Introduction to Java Applets—introduces another type of Java program, called an *applet*. Applets are Java programs designed to be transported over the Internet and executed in World Wide Web browsers (like Netscape Navigator and Microsoft Internet Explorer). The chapter introduces applets, using several of the demonstration applets supplied with the Java 2 Software Development Kit (J2SDK). We use ***appletviewer*** (a utility supplied with the J2SDK) or a Web browser to execute several sample applets. We then write Java applets that perform tasks similar to the programs of Chapter 2, and we explain the similarities and differences between applets and applications. After studying this chapter, the student will understand how to write simple, but complete, Java applets. The next several chapters use both applets and applications to demonstrate additional key programming concepts.

Chapter 4—Control Structures: Part 1—focuses on the program-development process. The chapter discusses how to take a *problem statement* (i.e., a *requirements document*) and from it develop a working Java program, including performing intermediate steps in pseudocode. The chapter introduces some fundamental data types and simple control structures used for decision making (**if** and **if/else**) and repetition (**while**). We examine counter-controlled repetition and sentinel-controlled repetition, and introduce Java's increment, decrement and assignment operators. The chapter uses simple flowcharts

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to show the flow of control through each of the control structures. The techniques discussed in Chapters 2 through 7 constitute a large part of what has been traditionally taught in the universities under the topic of structured programming. With Java, we do object-oriented programming. In doing so, we discover that the insides of the objects we build make abundant use of control structures. We have had a particularly positive experience assigning problems 4.11 through 4.14 in our introductory courses. Since these four problems have similar structure, doing all four is a nice way for students to "get the hang of" the program-development process. This chapter helps the student develop good programming habits in preparation for dealing with the more substantial programming tasks in the remainder of the text.

Chapter 5—Control Structures: Part 2—continues the discussions of Java control structures (**`for`**, the **`switch`** selection structure and the **`do/while`** repetition structure). The chapter explains the labeled **`break`** and **`continue`** statements with live-code examples. The chapter also contains a discussion of logical operators—**`&&`** (logical AND), **`&`** (boolean logical AND), **`||`** (logical OR), **`|`** (boolean logical inclusive OR), **`^`** (boolean logical exclusive OR) and **`!`** (NOT). There is a substantial exercise set including mathematical, graphical and business applications. Students will enjoy Exercise 5.25, which asks them to write a program with repetition and decision structures that prints the iterative song, "The Twelve Days of Christmas." The more mathematically inclined students will enjoy problems on binary, octal, decimal and hexadecimal number systems, calculating the mathematical constant π with an infinite series, Pythagorean triples and De Morgan's Laws. Our students particularly enjoy the challenges of triangle-printing and diamond-printing in Exercises 5.10, 5.18 and 5.20; these problems help students learn to deal with nested repetition structures—a complex topic to master in introductory courses.

Chapter 6—Methods—takes a deeper look inside objects. Objects contain data called instance variables and executable units called methods (these are often called *functions* in non-object-oriented procedural programming languages like C and *member functions* in C++). We explore methods in depth and include a discussion of methods that "call themselves," so-called recursive methods. We discuss class-library methods, programmer-defined methods and recursion. The techniques presented in Chapter 6 are essential to the production of properly structured programs, especially the kinds of larger programs and software that system programmers and application programmers are likely to develop in real-world applications. The "divide and conquer" strategy is presented as an effective means for solving complex problems by dividing them into simpler interacting components. Students enjoy the treatment of random numbers and simulation, and they appreciate the discussion of the dice game of craps that makes elegant use of control structures (this is one of our most successful lectures in our introductory courses). The chapter offers a solid introduction to recursion and includes a table summarizing the dozens of recursion examples and exercises distributed throughout the remainder of the book. Some texts leave recursion for a chapter late in the book; we feel this topic is best covered gradually throughout the text. The topic of method overloading (i.e., allowing multiple methods to have the same name as long as they have different "signatures") is motivated and explained clearly. We introduce *events* and *event handling*—elements required for programming graphical user interfaces. Events are notifications of state change such as button clicks, mouse clicks and pressing a keyboard key. Java allows programmers to specify the responses to events by coding methods called event handlers.

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The extensive collection of exercises at the end of the chapter includes several classical recursion problems such as the Towers of Hanoi; we revisit this problem later in the text where we employ graphics, animation and sound to make the problem "come alive." There are many mathematical and graphical examples. Our students particularly enjoy the development of a "Computer-Assisted Instruction" system in Exercises 6.31 through 6.33; we ask students to develop a multimedia version of this system later in the book. Students will enjoy the challenges of the "mystery programs." The more mathematically inclined students will enjoy problems on perfect numbers, greatest common divisors, prime numbers and factorials.

Chapter 7—Arrays—explores the processing of data in lists and tables of values. Arrays in Java are processed as objects, further evidence of Java's commitment to almost 100% object orientation. We discuss the structuring of data into arrays, or groups, of related data items of the same type. The chapter presents numerous examples of both single-subscripted arrays and double-subscripted arrays. It is widely recognized that structuring data properly is just as important as using control structures effectively in the development of properly structured programs. Examples in the chapter investigate various common array manipulations, printing histograms, sorting data, passing arrays to methods and an introduction to the field of survey data analysis (with simple statistics). A feature of this chapter is the discussion of elementary sorting and searching techniques and the presentation of binary searching as a dramatic improvement over linear searching. The end-of-chapter exercises include a variety of interesting and challenging problems, such as improved sorting techniques, the design of an airline reservations system, an introduction to the concept of turtle graphics (made famous in the LOGO programming language) and the Knight's Tour and Eight Queens problems that introduce the notions of heuristic programming so widely employed in the field of artificial intelligence. The exercises conclude with a series of recursion problems including the selection sort, palindromes, linear search, binary search, the eight queens, printing an array, printing a string backwards and finding the minimum value in an array. The chapter exercises include a delightful simulation of the classic race between the tortoise and the hare, card shuffling and dealing algorithms, recursive quicksort and recursive maze traversals. A special section entitled "Building Your Own Computer" explains machine-language programming and proceeds with the design and implementation of a computer simulator that allows the reader to write and run machine language programs. This unique feature of the text will be especially useful to the reader who wants to understand how computers really work. Our students enjoy this project and often implement substantial enhancements; many enhancements are suggested in the exercises. In Chapter 19, another special section guides the reader through building a compiler; the machine language produced by the compiler is then executed on the machine language simulator produced in Chapter 7. Information is communicated from the compiler to the simulator in sequential files (presented in Chapter 16).

Chapter 8—Object-Based Programming—begins our deeper discussion of classes. The chapter represents a wonderful opportunity for teaching data abstraction the "right way"—through a language (Java) expressly devoted to implementing abstract data types (ADTs). The chapter focuses on the essence and terminology of classes and objects. What is an object? What is a class of objects? What does the inside of an object look like? How are objects created? How are they destroyed? How do objects communicate with one another? Why are classes such a natural mechanism for packaging software as reusable

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componentry? The chapter discusses implementing ADTs as Java-style classes, accessing class members, enforcing information hiding with **`private`** instance variables, separating interface from implementation, using access methods and utility methods and initializing objects with constructors (and using overloaded constructors). The chapter discusses declaring and using constant references, *composition*—the process of building classes that have as members references to objects, the **`this`** reference that enables an object to "know itself," dynamic memory allocation, **`static`** class members for containing and manipulating class-wide data and examples of popular abstract data types such as stacks and queues. The chapter introduces the **`package`** statement and discusses how to create reusable packages. The chapter also introduces creating *Java archive (JAR)* files and demonstrates how to use JAR files to deploy applets that consist of multiple classes. The chapter exercises challenge the student to develop classes for complex numbers, rational numbers, times, dates, rectangles, huge integers, a class for playing Tic-Tac-Toe, a savings-account class and a class for holding sets of integers.

Chapter 9—Object-Oriented Programming—discusses the relationships among classes of objects and programming with related classes. How can we exploit commonality between classes of objects to minimize the amount of work it takes to build large software systems? What is polymorphism? What does it mean to "program in the general" rather than "program in the specific?" How does programming in the general make it easy to modify systems and add new features with minimal effort? How can we program for a whole category of objects rather than programming individually for each type of object? The chapter deals with one of the most fundamental capabilities of object-oriented programming languages, inheritance, which is a form of software reusability in which new classes are developed quickly and easily by absorbing the capabilities of existing classes and adding appropriate new capabilities. The chapter discusses the notions of superclasses and subclasses, **`protected`** members, direct superclasses, indirect superclasses, use of constructors in superclasses and subclasses, and software engineering with inheritance. This chapter introduces *inner classes* that help hide implementation details. Inner classes are most frequently used to create GUI event handlers. Named inner classes can be declared inside other classes and are useful in defining common event handlers for several GUI components. Anonymous inner classes are declared inside methods and are used to create one object—typically an event handler for a specific GUI component. The chapter compares inheritance ("is a" relationships) with composition ("has a" relationships). A feature of the chapter is its several substantial case studies. In particular, a lengthy case study implements a point, circle and cylinder class hierarchy. The exercises ask the student to compare the creation of new classes by inheritance vs. composition; to extend the inheritance hierarchies discussed in the chapter; to write an inheritance hierarchy for quadrilaterals, trapezoids, parallelograms, rectangles and squares and to create a more general shape hierarchy with two-dimensional shapes and three-dimensional shapes. The chapter explains polymorphic behavior. When many classes are related through inheritance to a common superclass, each subclass object may be treated as a superclass object. This enables programs to be written in a general manner independent of the specific types of the subclass objects. New kinds of objects can be handled by the same program, thus making systems more extensible. Polymorphism enables programs to eliminate complex **`switch`** logic in favor of simpler "straight-line" logic. A video game screen manager, for example, can send a "draw" message to every object in a linked list of objects to be drawn. Each object knows

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how to draw itself. A new type of object can be added to the program without modifying that program as long as that new object also knows how to draw itself. This style of programming is typically used to implement today's popular graphical user interfaces. The chapter distinguishes between **`abstract`** classes (from which objects *cannot* be instantiated) and concrete classes (from which objects *can* be instantiated). The chapter also introduces interfaces—sets of methods that must be defined by any class that **`implements`** the interface. Interfaces are Java's replacement for the dangerous (albeit powerful) feature of C++ called multiple inheritance.

Abstract classes are useful for providing a basic set of methods and default implementation to classes throughout the hierarchy. Interfaces are useful in many situations similar to **`abstract`** classes; however, interfaces do not include any implementation—interfaces have no method bodies and no instance variables. A feature of the chapter is its three major polymorphism case studies—a payroll system, a shape hierarchy headed up by an **`abstract`** class and a shape hierarchy headed up by an interface. The chapter exercises ask the student to discuss a number of conceptual issues and approaches, work with **`abstract`** classes, develop a basic graphics package, modify the chapter's employee class—and pursue all these projects with polymorphic programming.

Chapter 10—Strings and Characters—deals with processing words, sentences, characters and groups of characters. The key difference between Java and C here is that Java strings are objects. This makes string manipulation more convenient and much safer than in C where string and array manipulations are based on dangerous pointers. We present classes **`String`**, **`StringBuffer`**, **`Character`** and **`StringTokenizer`**. For each, we provide extensive live-code examples demonstrating most of their methods "in action." In all cases, we show output windows so that the reader can see the precise effects of each of the string and character manipulations. Students will enjoy the card shuffling and dealing example (which they will enhance in the exercises to the later chapters on graphics and multimedia). A key feature of the chapter is an extensive collection of challenging string-manipulation exercises related to limericks, pig Latin, text analysis, word processing, printing dates in various formats, check protection, writing the word equivalent of a check amount, Morse Code and metric-to-English conversions. Students will enjoy the challenges of developing their own spell checker and crossword-puzzle generator.

Advanced Topics

Chapters 11, 12 and 13 were coauthored with our colleague, Mr. Tem Nieto of Deitel & Associates, Inc. Tem's infinite patience, attention to detail, illustration skills and creativity are apparent throughout these chapters. [Take a fast peek at Figure 12.19 to see what happens when we turn Tem loose!]

Chapter 11—Graphics and Java2D—is the first of several chapters that present the multimedia "sizzle" of Java. We consider Chapters 11 through 22 to be the book's advanced material. This is "fun stuff." Traditional C and C++ programming are pretty much confined to character-mode input/output. Some versions of C++ are supported by platform-dependent class libraries that can do graphics, but using these libraries makes your applications nonportable. Java's graphics capabilities are platform independent and hence, portable—and we mean portable in a worldwide sense. You can develop graphics-intensive Java applets and distribute them over the World Wide Web to colleagues everywhere, and they will run nicely on the local Java platforms. We discuss graphics contexts

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and graphics objects; drawing strings, characters and bytes; color and font control; screen manipulation and paint modes and drawing lines, rectangles, rounded rectangles, three-dimensional rectangles, ovals, arcs and polygons. We introduce the Java2D API, which provides powerful graphical manipulation tools. Figure 11.22 is an example of how easy it is to use the Java2D API to create complex graphics effects such as textures and gradients. The chapter has 23 figures that painstakingly illustrate each of these graphics capabilities with live-code™ examples, appealing screen outputs, detailed features tables and detailed line art. Some of the 27 exercises challenge students to develop graphical versions of their solutions to previous exercises on Turtle Graphics, the Knight's Tour, the Tortoise and the Hare simulation, Maze Traversal and the Bucket Sort. Our companion book, *Advanced Java 2 Platform How to Program*, presents the Java 3D API.

Chapter 12—Graphical User Interface Components: Part 1—introduces the creation of applets and applications with user-friendly graphical user interfaces (GUIs). This chapter focuses on Java's *Swing GUI components*. These *platform-independent* GUI components are written entirely in Java. This provides Swing GUI components with great flexibility—the GUI components can be customized to look like the computer platform on which the program executes, or they can use the standard Java look-and-feel that provides an identical user interface across all computer platforms. GUI development is a huge topic, so we divided it into two chapters. These chapters cover the material in sufficient depth to enable you to build "industrial-strength" GUI interfaces. We discuss the **`javax.swing`** package, which provides much more powerful GUI components than the **`java.awt`** components that originated in Java 1.0. Through its 16 programs and many tables and line drawings, the chapter illustrates GUI principles, the **`javax.swing`** hierarchy, labels, push buttons, lists, text fields, combo boxes, checkboxes, radio buttons, panels, handling mouse events, handling keyboard events and using three of Java's simpler GUI layout managers, namely, **`FlowLayout`**, **`BorderLayout`** and **`GridLayout`**. The chapter concentrates on the delegation event model for GUI processing. The 33 exercises challenge the student to create specific GUIs, exercise various GUI features, develop drawing programs that let the user draw with the mouse and control fonts.

Chapter 13—Graphical User Interface Components: Part 2—continues the detailed Swing discussion started in Chapter 12. Through its 13 programs, as well as tables and line drawings, the chapter illustrates GUI design principles, the **`javax.swing`** hierarchy, text areas, subclassing Swing components, sliders, windows, menus, pop-up menus, changing the look-and-feel, and using three of Java's advanced GUI layout managers, namely, **`BoxLayout`**, **`CardLayout`** and **`GridBagLayout`**. Two of the most important examples introduced in this chapter are a program that can run as either an applet or application and a program that demonstrates how to create a *multiple document interface* (*MDI*) graphical user interface. MDI is a complex graphical user interface in which one window—called the *parent*—acts as the controlling window for the application. This parent window contains one or more child windows—which are always graphically displayed within the parent window. Most word processors use MDI graphical user interfaces. The chapter concludes with a series of exercises that encourage the reader to develop substantial GUIs with the techniques and components presented in the chapter. One of the most challenging exercises in this chapter is a complete drawing application that asks the reader to create an object oriented-program that keeps track of the shapes the user has drawn. Other exercises use inheritance to subclass Swing compo-

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nents and reinforce layout manager concepts. The first six chapters of our companion book, *Advanced Java 2 Platform How to Program*, are designed for courses in advanced GUI programming.

Chapter 14—Exception Handling—is one of the most important chapters in the book from the standpoint of building so-called "mission-critical" or "business-critical" applications that require high degrees of robustness and fault tolerance. Things do go wrong, and at today's computer speeds—commonly hundreds of millions operations per second (with recent personal computers running at a billion or more instructions per second)—if they can go wrong they will, and rather quickly at that. Programmers are often a bit naive about using components. They ask, "How do I request that a component do something for me?" They also ask "What value(s) does that component return to me to indicate it has performed the job I asked it to do?" But programmers also need to be concerned with, "What happens when the component I call on to do a job experiences difficulty? How will that component signal that it had a problem?" In Java, when a component (e.g., a class object) encounters difficulty, it can "throw an exception." The environment of that component is programmed to "catch" that exception and deal with it. Java's exception-handling capabilities are geared to an object-oriented world in which programmers construct systems largely from reusable, prefabricated components built by other programmers. To use a Java component, you need to know not only how that component behaves when "things go well," but also what exceptions that component throws when "things go poorly." The chapter distinguishes between rather serious system **`Error`**s (normally beyond the control of most programs) and **`Exception`**s (which programs generally deal with to ensure robust operation). The chapter discusses the vocabulary of exception handling. The **`try`** block executes program code that either executes properly or **`throw`**s an exception if something goes wrong. Associated with each **`try`** block are one or more **`catch`** blocks that handle thrown exceptions in an attempt to restore order and keep systems "up and running" rather than letting them "crash." Even if order cannot be fully restored, the **`catch`** blocks can perform operations that enable a system to continue executing, albeit at reduced levels of performance—such activity is often referred to as "graceful degradation." Regardless of whether exceptions are thrown, a **`finally`** block accompanying a **`try`** block will always execute; the **`finally`** block normally performs cleanup operations like closing files and releasing resources acquired in the **`try`** block. The material in this chapter is crucial to many of the live-code examples in the remainder of the book. The chapter enumerates many of the **`Error`**s and **`Exception`**s of the Java packages. The chapter has some of the most appropriate quotes in the book, thanks to Barbara Deitel's painstaking research. The vast majority of the book's Testing and Debugging Tips emerged naturally from the material in Chapter 14.

Chapter 15—Multithreading—deals with programming applets and applications that can perform multiple activities in parallel. Although our bodies are quite good at this (breathing, eating, blood circulation, vision, hearing, etc. can all occur in parallel), our conscious minds have trouble with this. Computers used to be built with a single, rather expensive processor. Today, processors are becoming so inexpensive that it is possible to build computers with many processors that work in parallel—such computers are called *multiprocessors*. The trend is clearly towards computers that can perform many tasks in parallel. Most of today's programming languages, including C and C++, do not include built-in features for expressing parallel operations. These languages are often referred to as "sequen-

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tial" programming languages or "single-thread-of-control" languages. Java includes capabilities to enable multithreaded applications (i.e., applications that can specify that multiple activities are to occur in parallel). This makes Java better prepared to deal with the more sophisticated multimedia, network-based multiprocessor-based applications programmers will develop. As we will see, multithreading is effective even on single-processor systems. For years, the "old guy" taught operating systems courses and wrote operating systems textbooks, but he never had a multithreaded language like Java available to demonstrate the concepts. In this chapter, we thoroughly enjoyed presenting multithreaded programs that demonstrate clearly the kinds of problems that can occur in parallel programming. There are all kinds of subtleties that develop in parallel programs that you simply never think about when writing sequential programs. A feature of the chapter is the extensive set of examples that show these problems and how to solve them. Another feature is the implementation of the "circular buffer," a popular means of coordinating control between asynchronous, concurrent "producer" and "consumer" processes that, if left to run without synchronization, would cause data to be lost or duplicated incorrectly, often with devastating results. We discuss the monitor construct developed by C. A. R. Hoare and implemented in Java; this is a standard topic in operating systems courses. The chapter discusses threads and thread methods. It walks through the various thread states and state transitions with a detailed line drawing showing the life-cycle of a thread. We discuss thread priorities and thread scheduling and use a line drawing to show Java's fixed-priority scheduling mechanism. We examine a producer/consumer relationship without synchronization, observe the problems that occur and solve the problem with thread synchronization. We implement a producer/consumer relationship with a circular buffer and proper synchronization with a monitor. We discuss daemon threads that "hang around" and perform tasks (e.g., "garbage collection") when processor time is available. We discuss interface **`Runnable`** which enables objects to run as threads without having to subclass class **`Thread`**. We close with a discussion of thread groups which, for example, enable separation to be enforced between system threads like the garbage collector and user threads. The chapter has a nice complement of exercises. The featured exercise is the classic readers and writers problem, a favorite in upper level operating systems courses; citations appear in the exercises for students who wish to research this topic. This is an important problem in database-oriented transaction-processing systems. It raises subtle issues of solving problems in concurrency control while ensuring that every separate activity that needs to receive service does so without the possibility of "indefinite postponement," that could cause some activities never to receive service—a condition also referred to as "starvation." Operating systems professors will enjoy the projects implemented by Java-literate students. We can expect substantial progress in the field of parallel programming as Java's multithreading capabilities enable large numbers of computing students to pursue parallel-programming class projects. As these students enter industry over the next several years, we expect a surge in parallel systems programming and parallel applications programming. We have been predicting this for decades—Java is making it a reality.

If this is your first Java book and you are an experienced computing professional, you may well be thinking, "Hey, this just keeps getting better and better. I can't wait to get started programming in this language. It will let me do all kinds of stuff I would like to do, but that was never easy for me to do with the other languages I have used." You've got it right. Java is an enabler. So, if you liked the multithreading discussion, hold onto your hat,

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because Java will let you program multimedia applications and make them available instantaneously over the World Wide Web.

Chapter 16—Files and Streams—deals with input/output that is accomplished through streams of data directed to and from files. This is one of the most important chapters for programmers who will be developing commercial applications. Modern business is centered around data. In this chapter, we translate data (objects) into a persistent format usable by other applications. Being able to store data in files or move it across networks (Chapter 17) makes it possible for programs to save data and to communicate with each other. This is the real strength of software today. The chapter begins with an introduction to the data hierarchy from bits, to bytes, to fields, to records, to files. Next, Java's simple view of files and streams is presented. We then present a walkthrough of the dozens of classes in Java's extensive input/output files and streams class hierarchy. We put many of these classes to work in live-code examples in this chapter and in Chapter 17. We show how programs pass data to secondary storage devices, like disks, and how programs retrieve data already stored on those devices. Sequential-access files are discussed using a series of three programs that show how to open and close files, how to store data sequentially in a file and how to read data sequentially from a file. Random-access files are discussed using a series of four programs that show how to create a file sequentially for random access, how to read and write data to a file with random access and how to read data sequentially from a randomly accessed file. The fourth random-access program combines many of the techniques of accessing files both sequentially and randomly into a complete transaction-processing program. We discuss buffering and how it helps programs that do significant amounts of input/output perform better. We discuss class **`File`** which programs use to obtain a variety of information about files and directories. We explain how objects can be output to, and input from, secondary storage devices. Students in our industry seminars have told us that, after studying the material on file processing, they were able to produce substantial file-processing programs that were immediately useful to their organizations. The exercises ask the student to implement a variety of programs that build and process sequential-access files and random-access files.

Chapter 17—Networking—deals with applets and applications that can communicate over computer networks. This chapter presents Java's lowest level networking capabilities. We write programs that "walk the Web." The chapter examples illustrate an applet interacting with the browser in which it executes, creating a mini Web browser, communicating between two Java programs using streams-based sockets and communicating between two Java programs using packets of data. A key feature of the chapter is the live-code implementation of a collaborative client/server Tic-Tac-Toe game in which two clients play Tic-Tac-Toe with one another arbitrated by a multithreaded server—great stuff! The multithreaded server architecture is exactly what is used today in popular UNIX and Windows NT network servers. The capstone example in the chapter is the Deitel Messenger case study, which simulates many of today's popular instant-messaging applications that enable computers users to communicate with friends, relatives and coworkers over the Internet. This 1130-line, multithreaded, client/server case study uses most of the programming techniques presented up to this point in the book. The messenger application also introduces multicasting, which enables a program to send packets of data to groups of clients. The chapter has a nice collection of exercises including several suggested modifications to the multithreaded server example. Our companion book, *Advanced Java 2 Platform*

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How to Program, offers a much deeper treatment of networking and distributed computing, with topics including remote method invocation (RMI), servlets, JavaServer Pages (JSP), Java 2 Enterprise Edition, wireless Java (and the Java 2 Micro Edition) and Common Object Request Broker Architecture (CORBA).

Chapter 18—Multimedia: Images, Animation and Audio—is the first of two chapters that present Java's capabilities for making computer applications come alive (Chapter 22 offers an extensive treatment of the Java Media Framework). It is remarkable that students in first programming courses will be writing applications with all these capabilities. The possibilities are intriguing. Imagine having access (over the Internet and through CD-ROM technology) to vast libraries of graphics images, audios and videos and being able to weave your own together with those in the libraries to form creative applications. Already, most new computers sold come "multimedia equipped." Students can create extraordinary term papers and classroom presentations with components drawn from vast public-domain libraries of images, line drawings, voices, pictures, videos, animations and the like. A "paper" when many of us were in the earlier grades was a collection of characters, possibly handwritten, possibly typewritten. A "paper" today can be a multimedia "extravaganza" that makes the subject matter come alive. It can hold your interest, pique your curiosity and make you feel what the subjects of the paper felt when they were making history. Multimedia is making science labs much more exciting. Textbooks are coming alive. Instead of looking at a static picture of some phenomenon, you can watch that phenomenon occur in a colorful, animated, presentation with sounds, videos and various other effects, leveraging the learning process. People are able to learn more, learn it in more depth and experience more viewpoints.

The chapter discusses images and image manipulation, audios and animation. A feature of the chapter is the image maps that enable a program to sense the presence of the mouse pointer over a region of an image, without clicking the mouse. We present a live-code image-map application with the icons from the programming tips you have seen in this chapter and will see throughout the book. As the user moves the mouse pointer across the seven icon images, the type of tip is displayed, either "Good Programming Practice" for the thumbs-up icon, "Portability Tip" for the bug with the suitcase icon and so on. Once you have read the chapter, you will be eager to try out all these techniques, so we have included 35 problems to challenge and entertain you (more are provided in Chapter 22). Here are some of the exercises that you may want to turn into term projects:

15 Puzzle
Analog Clock
Animation
Artist
Calendar/Tickler File
Calling Attention to an Image
Coloring Black and White Images
Crossword
Fireworks Designer
Game of Pool
Horse Race
Image Flasher
Image Zooming
Jigsaw Puzzle Generator
Kaleidoscope
Limericks
Maze Generator and Walker
Multimedia Simpletron Simulator
One-Armed Bandit
Random Inter-Image Transition
Randomly Erasing an Image
Reaction Time Tester
Rotating Images
Scrolling Image Marquee
Scrolling Text Marquee
Shuffleboard
Text Flasher

You are going to have a great time attacking these problems! Some will take a few hours and some are great term projects. We see all kinds of opportunities for multimedia electives starting to appear in the university computing curriculum. We hope you will have contests with your classmates to develop the best solutions to several of these problems.

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Chapter 19—Data Structures—is particularly valuable in second- and third-level university courses. The chapter discusses the techniques used to create and manipulate dynamic data structures, such as linked lists, stacks, queues (i.e., waiting lines) and trees. The chapter begins with discussions of self-referential classes and dynamic memory allocation. We proceed with a discussion of how to create and maintain various dynamic data structures. For each type of data structure, we present live-code programs and show sample outputs. Although it is valuable to know how these classes are implemented, Java programmers will quickly discover that many of the data structures they need are already available in class libraries, such as Java's own **`java.util`** that we discuss in Chapter 20 and Java **`Collection`**s that we discuss in Chapter 21. The chapter helps the student master Java-style references (i.e., Java's replacement for the more dangerous pointers of C and C++). One problem when working with references is that students could have trouble visualizing the data structures and how their nodes are linked together. So we present illustrations that show the links and the sequence in which they are created. The binary tree example is a nice capstone for the study of references and dynamic data structures. This example creates a binary tree; enforces duplicate elimination and introduces recursive preorder, inorder and postorder tree traversals. Students have a genuine sense of accomplishment when they study and implement this example. They particularly appreciate seeing that the inorder traversal prints the node values in sorted order. The chapter includes a substantial collection of exercises. A highlight of the exercises is the special section "Building Your Own Compiler." This exercise is based on earlier exercises that walk the student through the development of an infix-to-postfix conversion program and a postfix-expression evaluation program. We then modify the postfix evaluation algorithm to generate machine-language code. The compiler places this code in a file (using techniques the student mastered in Chapter 16). Students then run the machine language produced by their compilers on the software simulators they built in the exercises of Chapter 7! The many exercises include a supermarket simulation using queueing, recursively searching a list, recursively printing a list backwards, binary tree node deletion, level-order traversal of a binary tree, printing trees, writing a portion of an optimizing compiler, writing an interpreter, inserting/deleting anywhere in a linked list, analyzing the performance of binary tree searching and sorting and implementing an indexed list class.

Chapter 20—Java Utilities Package and Bit Manipulation—walks through the classes of the **`java.util`** package and discusses each of Java's bitwise operators. This is a nice chapter for reinforcing the notion of reuse. When classes already exist, it is much faster to develop software by simply reusing these classes than by "reinventing the wheel." Classes are included in class libraries because the classes are generally useful, correct, performance tuned, portability certified and/or for a variety of other reasons. Someone has invested considerable work in preparing these classes so why should you write your own? The world's class libraries are growing at a phenomenal rate. Given this, your skill and value as a programmer will depend on your familiarity with what classes exist and how you can reuse them cleverly to develop high-quality software rapidly. University data structures courses will be changing drastically over the next several years because most important data structures are already implemented in widely available class libraries. This chapter discusses many classes. Two of the most useful are **`Vector`** (a dynamic array that can grow and shrink as necessary) and **`Stack`** (a dynamic data structure that allows insertions and deletions from only one end—called the top—thus ensuring last-in-first-out behavior). The

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beauty of studying these two classes is that they are related through inheritance, as is discussed in Chapter 9, so the **java.util** package itself implements some classes in terms of others, thus avoiding reinventing the wheel and taking advantage of reuse. We also discuss classes **Dictionary**, **Hashtable**, **Properties** (for creating and manipulating persistent **Hashtable**s), **Random** and **BitSet**. The discussion of **BitSet** includes live code for one of the classic applications of **BitSet**s, namely the *Sieve of Eratosthenes*, used for determining prime numbers. The chapter discusses in detail Java's powerful bit-manipulation capabilities, which enable programmers to exercise lower level hardware capabilities. This helps programs process bit strings, set individual bits on or off and store information more compactly. Such capabilities—inherited from C—are characteristic of low-level assembly languages and are valued by programmers writing system software such as operating systems and networking software.

Chapter 21—Collections—discusses many of the Java 2 classes (of the **java.util** package) that provide predefined implementations of many of the data structures discussed in Chapter 19. This chapter, too, reinforces the notion of reuse. These classes are modeled after a similar class library in C++—the Standard Template Library. Collections provide Java programmers with a standard set of data structures for storing and retrieving data and a standard set of algorithms (i.e., procedures) that allow programmers to manipulate the data (such as searching for particular data items and sorting data into ascending or descending order). The chapter examples demonstrate collections, such as linked lists, trees, maps and sets, and algorithms for searching, sorting, finding the maximum value, finding the minimum value and so on. Each example clearly shows how powerful and easy to use collections are. The exercises suggest modifications to the chapter examples and ask the reader to reimplement data structures presented in Chapter 19 using collections.

Chapter 22—Java Media Framework and Java Sound—is the second of our two chapters dedicated to Java's tremendous multimedia capabilities. This chapter focusses on the Java Media Framework (JMF) and the Java Sound API. The Java Media Framework provides both audio and video capabilities. With the JMF, a Java program can play audio and video media and capture audio and video media from devices such as microphones and video cameras. Many of today's multimedia applications involve sending audio or video feeds across the Internet. For example, you can visit the **cnn.com** Web site to watch or listen to live news conferences, and many people listen to Internet-based radio stations through their Web browsers. The JMF enables Java developers to create so-called *streaming media* applications, in which a Java program sends live or recorded audio or video feeds across the Internet to other computers, then applications on those other computers play the media as it arrives over the network. The JavaSound APIs enable programs to manipulate Musical Instrument Digital Interface (MIDI) sounds and captured media (i.e., media from a device such as a microphone). This chapter concludes with a substantial MIDI-processing application that enables users to select MIDI files to play and record new MIDI files. Users can create their own MIDI music by interacting with the application's simulated synthesizer keyboard. In addition, the application can synchronize playing the notes in a MIDI file with pressing the keys on the simulated synthesizer keyboard—similar to a player piano! As with Chapter 18, once you read this chapter, you will be eager to try all these techniques, so we have included 44 additional multimedia exercises to challenge and entertain you. Some of the interesting projects include the following:

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Bouncing Ball Physics Demo
Craps
Digital Clock
Flight Simulator
Karaoke
Kinetics Physics Demo
Knight's Tour Walker
Morse Code
MP3 Player
Multimedia Authoring System
Pinball Machine
Roulette
Story Teller
Tic-Tac-Toe
Tortoise and the Hare
Towers of Hanoi
Video Conferencing
Video Games

Appendix A—Java Demos—presents a huge collection of some of the best Java demos available on the Web. Many of these sites make their source code available to you, so you can download the code and add your own features—a truly great way to learn Java! We encourage our students to do this, and we're amazed at the results! You should start your search by checking out the Sun Microsystems applet Web page, **`java.sun.com/applets`**. You can save time finding the best demos by checking out JARS (the Java Applet Rating Service) at **`www.jars.com`**. Here's a list of some of the demos mentioned in Appendix A (the URLs and descriptions of each are in Appendix A):

Animated SDSU Logo
Bumpy Lens 3D
Centipedo
Crazy Counter
Famous Curves Applet Index
Goldmine
Iceblox game
Java Game Park
Java4fun games
Missile Commando
PhotoAlbum II
Play A Piano
Sab's Game Arcade
SabBowl bowling game
Sevilla RDM 168
Stereoscopic 3D Hypercube
Teamball demos
Tube
Urbanoids
Warp 1.5

Appendix B—Java Resources—presents some of the best Java resources available on the Web. This is a great way for you to get into the "world of Java." The appendix lists various Java resources, such as consortia, journals and companies that make various key Java-related products. Here are some of the resources mentioned in Appendix B:

animated applets
applets/applications
arts and entertainment
audio sites
books
Borland JBuilder IDE
conferences
consultants
contests
CORBA homepage
current information
databases
demos (many with source code)
developer's kit
development tools
discussion groups
documentation
downloadable applets
FAQs (frequently asked ?s)
games
graphics
IBM Developers Java Zone
Intelligence.com
Java Applet Rating Service
Java Developer Connection
Java Developer's Journal
Java Media Framework
Java Report
Java tools
Java Toys
Java Users Group (JUGs)
Java Woman
`java.sun.com`
JavaWorld on-line magazine
learning Java
links to Java sites
lists of resources
lists of what is new and cool
live chat sessions on Java
multimedia collections
NASA multimedia gallery
NetBeans IDE
news
`news:comp.lang.java`
newsgroups
newsletters
Object Management Group
products
projects
publications
puzzles
reference materials
resources
seminars
sites
software
Sun Microsystems
SunWorld on-line magazine
Team Java
The Java Tutorial
trade shows
training (please call us!)
tutorials for learning java
URLs for Java applets
`www.javaworld.com`
Yahoo (Web search engine)

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Appendix C—Operator Precedence Chart—lists each of the Java operators and indicates their relative precedence and associativity. We list each operator on a separate line and include the full name of the operator.

Appendix D—ASCII Character Set—lists the characters of the ASCII (American Standard Code for Information Interchange) character set and indicates the character code value for each. Java uses the Unicode character set with 16-bit characters for representing all of the characters in the world's "commercially significant" languages. Unicode includes ASCII as a subset. Currently, most English-speaking countries are using ASCII and just beginning to experiment with Unicode.

Appendix E—Number Systems—discusses the binary (base 2), decimal (base 10), octal (base 8) and hexadecimal (base 16) number systems. This material is valuable for introductory courses in computer science and computer engineering. The appendix is presented with the same pedagogic learning aids as the chapters of the book. A nice feature of the appendix is its 31 exercises, 19 of which are self-review exercises with answers.

Appendix F—Creating `javadoc` Documentation—introduces the **`javadoc`** documentation-generation tool. Sun Microsystems uses **`javadoc`** to document the Java APIs. The example in this appendix takes the reader through the **`javadoc`** documentation process. First, we introduce the comment style and tags that **`javadoc`** recognizes and uses to create documentation. Next, we discuss the commands and options used to run the utility. Finally, we examine the source files **`javadoc`** uses and the HTML files **`javadoc`** creates.

1.18 (Optional) A Tour of the Case Study on Object-Oriented Design with the UML

In this and the next section, we tour the two optional major features of the book—the optional case study of object-oriented design with the UML and our introduction to design patterns. The case study involving object-oriented design with the UML is an important addition to *Java How to Program, Fourth Edition*. This tour previews the contents of the "Thinking About Objects" sections and discusses how they relate to the case study. After completing this case study, you will have completed an object-oriented design and implementation for a significant Java application.

Section 1.15—Thinking About Objects: Introduction to Object Technology and the Unified Modeling Language

This section introduces the object-oriented design case study with the UML. We provide a general background of what objects are and how they interact with other objects. We also discuss briefly the state of the software-engineering industry and how the UML has influenced object-oriented analysis and design processes.

Section 2.9—(Optional Case Study) Thinking About Objects: Examining the Problem Statement

Our case study begins with a *problem statement* that specifies the requirements for a system that we will create. In this case study, we design and implement a simulation of an elevator system in a two-story building. The application user can "create" a person on either floor. This person then walks across the floor to the elevator, presses a button, waits for the elevator to arrive and rides it to the other floor. We provide the design of our elevator system after investigating the structure and behavior of object-oriented systems in general. We dis-

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cuss how the UML will facilitate the design process in subsequent "Thinking About Object" sections by providing us with several types of diagrams to model our system. Finally, we provide a list of URL and book references on object-oriented design with the UML. You might find these references helpful as you proceed through our case-study presentation.

Section 3.8—(Optional Case Study) Thinking About Objects: Identifying the Classes in the Problem Statement

In this section, we design the elevator-simulation model, which represents the operations of the elevator system. We identify the classes, or "building blocks," of our model by extracting the nouns and noun phrases from the problem statement. We arrange these classes into a UML class diagram that describes the class structure of our model. The class diagram also describes relationships, known as *associations*, among classes (for example, a person has an association with the elevator, because the person rides the elevator). Lastly, we extract from the class diagram another type of diagram in the UML—the object diagram. The object diagram models the objects (instances of classes) at a specific time in our simulation.

Section 4.14—(Optional Case Study) Thinking About Objects: Identifying Class Attributes

A class contains both *attributes* (data) and *operations* (behaviors). This section focuses on the attributes of the classes discussed in Section 3.7. As we see in later sections, changes in an object's attributes often affect the behavior of that object. To determine the attributes for the classes in our case study, we extract the adjectives describing the nouns and noun phrases (which defined our classes) from the problem statement, then place the attributes in the class diagram we create in Section 3.7.

Section 5.11—(Optional Case Study) Thinking About Objects: Identifying Objects' States and Activities

An object, at any given time, occupies a specific condition called a *state*. A *state transition* occurs when that object receives a message to change state. The UML provides the *statechart diagram*, which identifies the set of possible states that an object may occupy and models that object's state transitions. An object also has an *activity*—the work performed by an object in its lifetime. The UML provides the *activity diagram*—a flowchart that models an object's *activity*. In this section, we use both types of diagrams to begin modeling specific behavioral aspects of our elevator simulation, such as how a person rides the elevator and how the elevator responds when a button is pressed on a given floor.

Section 6.16—(Optional Case Study) Thinking About Objects: Identifying Class Operations

In this section, we identify the operations, or services, of our classes. We extract from the problem statement the verbs and verb phrases that specify the operations for each class. We then modify the class diagram of Fig. 3.16 to include each operation with its associated class. At this point in the case study, we will have gathered all information possible from the problem statement. However, as future chapters introduce such topics as inheritance, event-handling and multithreading, we will modify our classes and diagrams.

Section 7.10—(Optional Case Study) Thinking About Objects: Collaboration Among Objects

At this point, we have created a "rough sketch" of the model for our elevator system. In this section, we see how it works. We investigate the behavior of the model by discussing *col-*

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laborations—messages that objects send to each other to communicate. The class operations that we discovered in Section 6.16 turn out to be the collaborations among the objects in our system. We determine the collaborations in our system, then collect them into a *collaboration diagram*—the UML diagram for modeling collaborations. This diagram reveals which objects collaborate and when. We present a collaboration diagram of the people entering and exiting the elevator.

Section 8.17—(Optional Case Study) Thinking About Objects: Starting to Program the Classes for the Elevator Simulation

In this section, we take a break from designing the behavior of our system. We begin the implementation process to emphasize the material discussed in Chapter 8. Using the UML class diagram of Section 3.7 and the attributes and operations discussed in Sections 4.14 and 6.16, we show how to implement a class in Java from a design. We do not implement all classes—because we have not completed the design process. Working from our UML diagrams, we create code for the **`Elevator`** class.

Section 9.23—(Optional Case Study) Thinking About Objects: Incorporating Inheritance into the Elevator Simulation

Chapter 9 begins our discussion of object-oriented programming. We consider inheritance—classes sharing similar characteristics may inherit attributes and operations from a "base" class. In this section, we investigate how our elevator simulation can benefit from using inheritance. We document our discoveries in a class diagram that models inheritance relationships—the UML refers to these relationships as *generalizations*. We modify the class diagram of Section 3.7 by using inheritance to group classes with similar characteristics. We continue implementing the **`Elevator`** class of Section 8.17 by incorporating inheritance.

Section 10.22—(Optional Case Study) Thinking About Objects: Event Handling

In this section, we include interfaces necessary for the objects in our elevator simulation to send messages to other objects. In Java, objects often communicate by sending an *event*—a notification that some action has occurred. The object receiving the event then performs an action in response to the type of event received—this is known as *event handling*. In Section 7.10, we outlined the message passing, or the collaborations, in our model, using a collaboration diagram. We now modify this diagram to include event handling, and, as an example, we explain in detail how doors in our simulation open upon the elevator's arrival.

Section 11.10—(Optional Case Study) Thinking About Objects: Designing Interfaces with the UML

In this section, we design a class diagram that models the relationships between classes and interfaces in our simulation—the UML refers to these relationships as *realizations*. In addition, we list all operations that each interface provides to the classes. Lastly, we show how to create the Java classes that implement these interfaces. As in Section 8.17 and Section 9.23, we use class **`Elevator`** to demonstrate the implementation.

Section 12.16 - (Optional Case Study) Thinking About Objects: Use Cases

Chapter 12 discusses user interfaces that enable a user to interact with a program. In this section, we discuss the interaction between our elevator simulation and its user. Specifically, we investigate the scenarios that may occur between the application user and the simu-

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lation itself—this set of scenarios is called a *use case*. We model these interactions, using *use-case diagrams* of the UML. We then discuss the graphical user interface for our simulation, using our use-case diagrams.

Section 13.17—(Optional Case Study) Thinking About Objects: Model-View-Controller
We designed our system to consist of three components, each having a distinct responsibility. By this point in the case study, we have almost completed the first component, called the *model*, which contains data that represent the simulation. We design the *view*—the second component, dealing with how the model is displayed—in Section 22.8. We design the *controller*—the component that allows the user to control the model—in Section 12.16. A system such as ours that uses the model, view and controller components is said to adhere to *Model-View-Controller* (*MVC*) architecture. In this section, we explain the advantages of using this architecture to design software. We use the UML *component diagram* to model the three components, then implement this diagram as Java code.

Section 15.12—(Optional Case Study) Thinking About Objects: Multithreading
In the real world, objects operate and interact concurrently. Java is a *multithreaded* language, which enables the objects in our simulation to act seemingly independently from each other. In this section, we declare certain objects as "threads" to enable these objects to operate concurrently. We modify the collaboration diagram originally presented in Section 7.10 (and modified in Section 10.22) to incorporate multithreading. We present the UML *sequence diagram* for modeling interactions in a system. This diagram emphasizes the chronological ordering of messages. We use a sequence diagram to model how a person inside the simulation interacts with the elevator. This section concludes the design of the model portion of our simulation. We design how this model is displayed in Section 22.9, then implement this model as Java code in Appendix H.

Section 22.9—(Optional Case Study) Thinking About Objects: Animation and Sound in the View
This section designs the view, which specifies how the model portion of the simulation is displayed. Chapter 18 presents several techniques for integrating animation in programs, and Chapter 22 presents techniques for integrating sound. Section 22.9 uses some of these techniques to incorporate sound and animation into our elevator simulation. Specifically, this section deals with animating the movements of people and our elevator, generating sound effects and playing "elevator music" when a person rides the elevator. This section concludes the design of our elevator simulation. Appendices G, H and I implement this design as a 3,594-line, fully operational Java program.

Appendix G—Elevator Events and Listener Interfaces
[Note: This appendix is on the CD that accompanies this book.] As we discussed in Section 10.22, several objects in our simulation interact with each other by sending messages, called events, to other objects wishing to receive these events. The objects receiving the events are called *listener objects*—these must implement *listener interfaces*. In this section, we implement all event classes and listener interfaces used by the objects in our simulation.

Appendix H—Elevator Model
[Note: This appendix is on the CD that accompanies this book.] The majority of the case study involved designing the model (i.e., the data and logic) of the elevator simulation. In

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this section, we implement that model in Java. Using all the UML diagrams we created, we present the Java classes necessary to implement the model. We apply the concepts of object-oriented design with the UML and object-oriented programming and Java that you learned in the chapters.

Appendix I—Elevator View
[Note: This appendix is on the CD that accompanies this book.] The final section implements how we display the model from Appendix H. We use the same approach to implement the view as we used to implement the model—we create all the classes required to run the view, using the UML diagrams and key concepts discussed in the chapters. By the end of this section, you will have completed an "industrial-strength" design and implementation of a large-scale system. You should feel confident tackling larger systems, such as the 8000-line Enterprise Java case study we present in our companion book *Advanced Java 2 Platform How to Program* and the kinds of applications that professional software engineers build. Hopefully, you will move on to even deeper study of object-oriented design with the UML.

1.19 (Optional) A Tour of the "Discovering Design Patterns" Sections

Our treatment of design patterns is spread over five optional sections of the book. We overview those sections here.

Section 9.24—(Optional) Discovering Design Patterns: Introducing Creational, Structural and Behavioral Design Patterns
This section provides tables that list the sections in which we discuss the various design patterns. We divide the discussion of each section into creational, structural and behavioral design patterns. Creational patterns provide ways to instantiate objects, structural patterns deal with organizing objects and behavioral patterns deal with interactions between objects. The remainder of the section introduces some of these design patterns, such as the Singleton, Proxy, Memento and State design patterns. Finally, we provide several URLs for further study on design patterns.

Section 13.18—(Optional) Discovering Design Patterns: Design Patterns Used in Packages `java.awt` and `javax.swing`
This section contains most of our design-patterns discussion. Using the material on Java Swing GUI components in Chapters 12 and 13, we investigate some examples of pattern use in packages **`java.awt`** and **`javax.swing`**. We discuss how these classes use the Factory Method, Adapter, Bridge, Composite, Chain-of-Responsibility, Command, Observer, Strategy and Template Method design patterns. We motivate each pattern and present examples of how to apply them.

Section 15.13—(Optional) Discovering Design Patterns: Concurrent Design Patterns
Developers have introduced several design patterns since those described by the gang of four. In this section, we discuss concurrency design patterns, including Single-Threaded Execution, Guarded Suspension, Balking, Read/Write Lock and Two-Phase Termination—these solve various design problems in multithreaded systems. We investigate how class **`java.lang.Thread`** uses concurrency patterns.

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Section 17.11—(Optional) Discovering Design Patterns: Design Patterns Used in Packages `java.io` and `java.net`

Using the material on files, streams and networking in Chapters 16 and 17, we investigate some examples of pattern use in packages **`java.io`** and **`java.net`**. We discuss how these classes use the Abstract Factory, Decorator and Facade design patterns. We also consider architectural patterns, which specify a set of subsystems—aggregates of objects that each collectively comprise a major system responsibility—and how these subsystems interact with each other. We discuss the popular Model-View-Controller and Layers architectural patterns.

Section 21.12—(Optional) Discovering Design Patterns: Design Patterns Used in Package `java.util`

Using the material on data structures and collections in Chapters 19, 20 and 21, we investigate pattern use in package **`java.util`**. We discuss how these classes use the Prototype and Iterator design patterns. This section concludes the discussion on design patterns. After finishing the *Discovering Design Patterns* material, you should be able to recognize and use key design patterns and have a better understanding of the workings of the Java API. After completing this material, we recommend that you move on to the gang-of-four book.

Well, there you have it! We have worked hard to create this book and its optional Cyber Classroom version. The book is loaded with live-code examples, programming tips, self-review exercises and answers, challenging exercises and projects, and numerous study aids to help you master the material. Java is a powerful programming language that will help you write programs quickly and effectively. And Java is a language that scales nicely into the realm of enterprise-systems development to help organizations build their key information systems. As you read the book, if something is not clear, or if you find an error, please write to us at **`deitel@deitel.com`**. We will respond promptly, and we will post corrections and clarifications on our Web site,

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We hope you enjoy learning with *Java How to Program: Fourth Edition* as much as we enjoyed writing it!

SUMMARY

- Software controls computers (often referred to as hardware).
- Java is one of today's most popular software-development languages.
- Java was developed by Sun Microsystems. Sun provides an implementation of the Java 2 Platform, Standard Edition called the Java 2 Software Development Kit (J2SDK), version 1.3.1 that includes the minimum set of tools you need to write software in Java.
- Java is a fully object-oriented language with strong support for proper software-engineering techniques.
- A computer is a device capable of performing computations and making logical decisions at speeds millions, even billions, of times faster than human beings can.
- Computers process data under the control of sets of instructions called computer programs. These computer programs guide the computer through orderly sets of actions specified by people called computer programmers.

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- The various devices that comprise a computer system (such as the keyboard, screen, disks, memory and processing units) are referred to as hardware.
- The computer programs that run on a computer are referred to as software.
- The input unit is the "receiving" section of the computer. It obtains information (data and computer programs) from various input devices and places this information at the disposal of the other units so that the information may be processed.
- The output unit is the "shipping" section of the computer. It takes information processed by the computer and places it on output devices to make it available for use outside the computer.
- The memory unit is the rapid access, relatively low-capacity "warehouse" section of the computer. It retains information that has been entered through the input unit so that the information may be made immediately available for processing when it is needed and retains information that has already been processed until that information can be placed on output devices by the output unit.
- The arithmetic and logic unit (ALU) is the "manufacturing" section of the computer. It is responsible for performing calculations such as addition, subtraction, multiplication and division and for making decisions.
- The central processing unit (CPU) is the "administrative" section of the computer. It is the computer's coordinator and is responsible for supervising the operation of the other sections.
- The secondary storage unit is the long-term, high-capacity "warehousing" section of the computer. Programs or data not being used by the other units are normally placed on secondary storage devices (such as disks) until they are needed, possibly hours, days, months or even years later.
- Early computers were capable of performing only one job or task at a time. This form of computer operation often is called single-user batch processing.
- Software systems called operating systems were developed to help make it more convenient to use computers. Early operating systems managed the smooth transition between jobs and minimized the time it took for computer operators to switch between jobs.
- Multiprogramming involves the "simultaneous" operation of many jobs on the computer—the computer shares its resources among the jobs competing for its attention.
- Timesharing is a special case of multiprogramming in which dozens or even hundreds of users share a computer through terminals. The computer runs a small portion of one user's job, then moves on to service the next user. The computer does this so quickly that it might provide service to each user several times per second, so programs appear to run simultaneously.
- An advantage of timesharing is that the user receives almost immediate responses to requests rather than having to wait long periods for results, as with previous modes of computing.
- In 1977, Apple Computer popularized the phenomenon of personal computing.
- In 1981, IBM introduced the IBM Personal Computer. Almost overnight, personal computing became legitimate in business, industry and government organizations.
- Although early personal computers were not powerful enough to timeshare several users, these machines could be linked together in computer networks, sometimes over telephone lines and sometimes in local area networks (LANs) within an organization. This led to the phenomenon of distributed computing, in which an organization's computing is distributed over networks to the sites at which the real work of the organization is performed.
- Today, information is shared easily across computer networks where some computers called file servers offer a common store of programs and data that may be used by client computers distributed throughout the network—hence the term client/server computing.
- Java has become the language of choice for developing Internet-based applications (and for many other purposes).

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- Computer languages may be divided into three general types: machine languages, assembly languages and high-level languages.
- Any computer can directly understand only its own machine language. Machine languages generally consist of strings of numbers (ultimately reduced to 1s and 0s) that instruct computers to perform their most elementary operations one at a time. Machine languages are machine dependent.
- English-like abbreviations formed the basis of assembly languages. Translator programs called assemblers convert assembly-language programs to machine language at computer speeds.
- Compilers translate high-level language programs into machine-language programs. High-level languages (like Java) contain English words and conventional mathematical notations.
- Interpreter programs directly execute high-level language programs without the need for compiling those programs into machine language.
- Although compiled programs execute much faster than interpreted programs, interpreters are popular in program-development environments in which programs are recompiled frequently as new features are added and errors are corrected.
- Objects are essentially reusable software components that model items in the real world. Modular, object-oriented design and implementation approaches make software-development groups more productive than is possible with previous popular programming techniques such as structured programming. Object-oriented programs are often easier to understand, correct and modify.
- Java originated at Sun Microsystems as a project for intelligent consumer-electronic devices.
- When the World Wide Web exploded in popularity in 1993, Sun people saw the immediate potential of using Java to create Web pages with so-called dynamic content.
- Java is now used to create Web pages with dynamic and interactive content, to develop large-scale enterprise applications, to enhance the functionality of Web servers, to provide applications for consumer devices and so on.
- Java programs consist of pieces called classes. Classes consist of pieces called methods that perform tasks and return information when they complete their tasks.
- Most Java programmers use rich collections of existing classes in Java class libraries.
- FORTRAN (FORmula TRANslator) was developed by IBM Corporation between 1954 and 1957 for scientific and engineering applications that require complex mathematical computations.
- COBOL (COmmon Business Oriented Language) was developed in 1959 by a group of computer manufacturers and government and industrial computer users. COBOL is used primarily for commercial applications that require precise and efficient manipulation of large amounts of data.
- Pascal was designed at about the same time as C. It was created by Professor Nicklaus Wirth and was intended for academic use.
- Basic was developed in 1965 at Dartmouth College as a simple language to help novices become comfortable with programming.
- Structured programming is a disciplined approach to writing programs that are clearer than unstructured programs, easier to test and debug and easier to modify.
- The Ada language was developed under the sponsorship of the United States Department of Defense (DOD) during the 1970s and early 1980s. One important capability of Ada is called multitasking; this allows programmers to specify that many activities are to occur in parallel.
- Most high-level languages—including C and C++—generally allow the programmer to write programs that perform only one activity at a time. Java, through a technique called multithreading, enables programmers to write programs with parallel activities.
- The Internet was developed more than three decades ago with funding supplied by the Department of Defense. Originally designed to connect the main computer systems of about a dozen universi-

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ties and research organizations, the Internet today is accessible by hundreds of millions of computers worldwide.

- The Web allows computer users to locate and view multimedia-intensive documents over the Internet.
- Java systems generally consist of several parts: an environment, the language, the Java Applications Programming Interface (API) and various class libraries.
- Java programs normally go through five phases to be executed—edit, compile, load, verify and execute.
- Java program file names end with the **`.java`** extension.
- The Java compiler (**`javac`**) translates a Java program into bytecodes—the language understood by the Java interpreter. If a program compiles correctly, the compiler produces a file with the **`.class`** extension. This is the file containing the bytecodes that are interpreted during the execution phase.
- A Java program must first be placed in memory before it can execute. This is done by the class loader, which takes the **`.class`** file (or files) containing the bytecodes and transfers it to memory. The **`.class`** file can be loaded from a disk on your system or over a network.
- An application is a program that is normally stored and executed on the user's local computer.
- An applet is a small program that is normally stored on a remote computer that users connect to via a Web browser. Applets are loaded from a remote computer into the browser, executed in the browser and discarded when execution completes.
- Applications are loaded into memory, then executed by the **`java`** interpreter.
- Browsers are used to view HTML (Hypertext Markup Language) documents on the World Wide Web.
- When the browser sees an applet in an HTML document, the browser launches the Java class loader to load the applet. The browsers that support Java each have a built-in Java interpreter. Once the applet is loaded, the Java interpreter in the browser begins executing the applet.
- Applets can also be executed from the command line using the **`appletviewer`** command provided with the Java 2 Software Development Kit (J2SDK). The **`appletviewer`** is commonly referred to as the minimum browser—it knows only how to interpret applets.
- Before the bytecodes in an applet are executed by the Java interpreter built into a browser or the **`appletviewer`**, they are verified by the bytecode verifier to ensure that the bytecodes for downloaded classes are valid and that they do not violate Java's security restrictions.
- An intermediate step between interpreters and compilers is a just-in-time (JIT) compiler that, as the interpreter runs, produces compiled code for the programs and executes the programs in machine language rather than reinterpreting them. JIT compilers do not produce machine language that is as efficient as a full compiler.
- For organizations wanting to do heavy-duty information-systems development, Integrated Development Environments (IDEs) are available from the major software suppliers. The IDEs provide many tools for supporting the software-development process.
- Object orientation is a natural way of thinking about the world and of writing computer programs.
- The Unified Modeling Language (UML) is a graphical language that allows people who build systems to represent their object-oriented designs in a common notation.
- Humans think in terms of objects. We possess the marvelous ability of abstraction, which enables us to view screen images as people, planes, trees and mountains rather than as individual dots of color (called pixels—for "picture elements").

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- Humans learn about objects by studying their attributes and observing their behaviors. Different objects can have similar attributes and can exhibit similar behaviors.
- Object-oriented design (OOD) models real-world objects. It takes advantage of class relationships, where objects of a certain class—such as a class of vehicles—have the same characteristics. It takes advantage of inheritance relationships, and even multiple-inheritance relationships, where newly created classes of objects are derived by absorbing characteristics of existing classes and adding unique characteristics of their own.
- OOD encapsulates data (attributes) and functions (behavior) into objects; the data and functions of an object are intimately tied together.
- Objects have the property of information hiding. This means that, although objects may know how to communicate with one another across well-defined interfaces, objects normally are not allowed to know how other objects are implemented.
- Languages such as Java are object-oriented—programming in such a language is called object-oriented programming (OOP) and allows designers to implement the object-oriented design as a working system.
- In Java, the unit of programming is the class from which objects are eventually instantiated (a fancy term for "created"). Java classes contain methods (which implement class behaviors) and attributes (which implement class data).
- Java programmers concentrate on creating their own user-defined types, called classes. Each class contains data and the set of functions that manipulate that data. The data components of a Java class are called attributes. The function components of a Java class are called methods.
- An instance of a user-defined type (i.e., a class) is called an object.
- Classes can also have relationships with other classes. These relationships are called associations.
- With object technology, we can build much of the software we will need by combining "standardized, interchangeable parts" called classes.
- The process of analyzing and designing a system from an object-oriented point of view is called object-oriented analysis and design (OOAD).
- The Unified Modeling Language (the UML) is now the most widely used graphical representation scheme for modeling object-oriented systems. Those who design systems use the language (in the form of graphical diagrams) to model their systems.
- Over the past decade, the software-engineering industry has made significant progress in the field of design patterns—proven architectures for constructing flexible and maintainable object-oriented software. Using design patterns can substantially reduce the complexity of the design process.
- Design patterns benefit system developers by helping to construct reliable software using proven architectures and accumulated industry expertise, promoting design reuse in future systems, identifying common mistakes and pitfalls that occur when building systems, helping to design systems independently of the language in which they will be implemented, establishing a common design vocabulary among developers and shortening the design phase in a software-development process.
- Designers use design patterns to construct sets of classes and objects.
- Creational design patterns describe techniques to instantiate objects (or groups of objects).
- Structural design patterns allow designers to organize classes and objects into larger structures.
- Behavioral design patterns assign responsibilities to objects.

TERMINOLOGY

abstraction
Ada
ALU (arithmetic and logic unit)
ANSI C

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applet
`appletviewer` command
application
arithmetic and logic unit (ALU)
array
assembly language
attribute
Basic
behavior
behavioral design pattern
bytecode
bytecode verifier
C
C standard library
C++
central processing unit (CPU)
class
`.class` file
class libraries
class loader
client/server computing
COBOL
collections
compile phase
compiler
compile-time error
computer
computer program
computer programmer
condition
CPU (central processing unit)
creational design pattern
design pattern
disk
distributed computing
dynamic content
edit phase
editor
encapsulation
event-driven programming
execute phase
execution-time error
fatal runtime error
file server
Fortran
freeware
hardware
high-level language
HotSpot compiler
HTML (Hypertext Markup Language)
IDE (Integrated Development Environment)
information hiding
inheritance
input device
input unit
input/output (I/O)
instance variable
Internet
interpreter
Java
`.java` extension
Java 2 Software Development Kit (J2SDK)
`java` interpreter
Java Virtual Machine
`javac` compiler
JIT (just-in-time) compiler
KIS (keep it simple)
legacy systems
live-code™ approach
load phase
logic error
machine dependent
machine independent
machine language
memory unit
method
Microsoft
Microsoft Internet Explorer Web browser
modeling
multiprocessor
multitasking
multithreading
Netscape Navigator Web browser
nonfatal run-time error
object
object
object-oriented analysis and design (OOAD)
object-oriented design (OOD)
object-oriented programming (OOP)
open source
output device
output unit
Pascal
personal computing
platforms
portability
primary memory
problem statement
procedural programming
programming language

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reference
requirements document
reusable componentry
runtime error
secondary storage unit
shareware
software
software reuse
structural design pattern
structured programming
Sun Microsystems
Swing GUI components
syntax error
throughput
throw an exception
timesharing
translator programs
Unified Modeling Language (UML)
verify phase
video
World Wide Web

SELF-REVIEW EXERCISES

1.1 Fill in the blanks in each of the following statements:

a) The company that popularized personal computing was _____.
b) The computer that made personal computing legitimate in business and industry was the _____.
c) Computers process data under the control of sets of instructions called _____.
d) The six key logical units of the computer are the _____, _____, _____, _____, _____ and _____.
e) The three classes of languages discussed in the chapter are _____, _____ and _____.
f) The programs that translate high-level language programs into machine language are called _____.

1.2 Fill in the blanks in each of the following sentences about the Java environment:

a) The _____ command from the Java 2 Software Development Kit executes a Java applet.
b) The _____ command from the Java 2 Software Development Kit executes a Java application
c) The _____ command from the Java 2 Software Development Kit compiles a Java program.
d) A(n) _____ file is required to invoke a Java applet.
e) A Java program file must end with the _____ file extension.
f) When a Java program is compiled, the file produced by the compiler ends with the _____ file extension.
g) The file produced by the Java compiler contains _____ that are interpreted to execute a Java applet or application.

1.3 Fill in the blanks in each of the following statements:

a) The _____ allows computer users to locate and view multimedia-based documents on almost any subject over the Internet.
b) Java _____ typically are stored on your computer and are designed to execute independent of a World Wide Web browsers.
c) Lists and tables of values are called _____.
d) The _____ GUI components are written completely in Java.
e) _____ allows an applet or application to perform multiple activities in parallel.
f) _____ provide Java programmers with a standard set of data structures for storing and retrieving data and a standard set of algorithms that allow programmers to manipulate the data.

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1.4 Fill in the blanks in each of the following statements (based on Sections 1.15 and 1.16):

a) Over the past decade, the software-engineering industry has made significant progress in the field of _____—proven architectures for constructing flexible and maintainable object-oriented software.

b) Objects have the property of _____.

c) Java programmers concentrate on creating their own user-defined types, called _____.

d) Classes can also have relationships with other classes. These relationships are called _____.

e) The process of analyzing and designing a system from an object-oriented point of view is called _____.

ANSWERS TO SELF-REVIEW EXERCISES

1.1 a) Apple. b) IBM Personal Computer. c) programs. d) input unit, output unit, memory unit, arithmetic and logic unit, central processing unit, secondary storage unit. e) machine languages, assembly languages, high-level languages. f) compilers.

1.2 a) **`appletviewer`**. b) **`java`**. c) **`javac`**. d) HTML. e) **`.java`**. f) **`.class`**. g) bytecodes.

1.3 a) World Wide Web. b) applications. c) arrays. d) Swing. e) Multithreading. f) Collections.

1.4 a) design patterns. b) information hiding. c) classes. d) associations. e) object-oriented analysis and design (OOAD).

EXERCISES

1.5 Categorize each of the following items as either hardware or software:

a) CPU

b) Java compiler

c) ALU

d) Java interpreter

e) input unit

f) editor

1.6 Why might you want to write a program in a machine-independent language instead of a machine-dependent language? Why might a machine-dependent language be more appropriate for writing certain types of programs?

1.7 Fill in the blanks in each of the following statements:

a) Which logical unit of the computer receives information from outside the computer for use by the computer? _____.

b) The process of instructing the computer to solve specific problems is called _____.

c) What type of computer language uses English-like abbreviations for machine language instructions? _____.

d) Which logical unit of the computer sends information that has already been processed by the computer to various devices so that the information may be used outside the computer? _____.

e) Which logical unit of the computer retains information? _____.

f) Which logical unit of the computer performs calculations? _____.

g) Which logical unit of the computer makes logical decisions? _____.

h) The level of computer language most convenient to the programmer for writing programs quickly and easily is _____.

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i) The only language that a computer can directly understand is called that computer's _____.

j) Which logical unit of the computer coordinates the activities of all the other logical units? _____.

1.8 Distinguish between the terms fatal error and nonfatal error. Why might you prefer to experience a fatal error rather than a nonfatal error?

1.9 Fill in the blanks in each of the following statements:

a) Java _____ are designed to be transported over the Internet and executed in World Wide Web browsers.

b) _____ programming causes a program to perform a task in response to user interactions with graphical user interface (GUI) components.

c) Java's graphics capabilities are _____ and, hence portable.

d) The standard _____ can be used to provide identical user interfaces across all computer platforms.

e) Languages that cannot perform multiple activities in parallel are called _____ languages or _____ languages.

f) Aggregations of data such as linked lists, stacks, queues and trees are called _____.

1.10 Fill in the blanks in each of the following statements (based on Sections 1.15 and 1.16):

a) _____ design patterns describe techniques to instantiate objects (or groups of objects).

b) The _____ is now the most widely used graphical representation scheme for modeling object-oriented systems.

c) Java classes contain _____ (which implement class behaviors) and (which implement class data).

d) _____ design patterns allow designers to organize classes and objects into larger structures.

e) _____ design patterns assign responsibilities to objects.

f) In Java, the unit of programming is the _____, from which _____ are eventually instantiated.

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2

Introduction to Java Applications

Objectives

- To be able to write simple Java applications.
- To be able to use input and output statements.
- To become familiar with primitive data types.
- To understand basic memory concepts.
- To be able to use arithmetic operators.
- To understand the precedence of arithmetic operators.
- To be able to write decision-making statements.
- To be able to use relational and equality operators.

Comment is free, but facts are sacred.
C. P. Scott

The creditor hath a better memory than the debtor.
James Howell

When faced with a decision, I always ask, "What would be the most fun?"
Peggy Walker

He has left his body to science—
and science is contesting the will.
David Frost

Classes struggle, some classes triumph, others are eliminated.
Mao Zedong

Equality, in a social sense, may be divided into that of condition and that of rights.
James Fenimore Cooper

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Outline

2.1 Introduction
2.2 A First Program in Java: Printing a Line of Text
2.2.1 Compiling and Executing your First Java Application
2.3 Modifying Our First Java Program
2.3.1 Displaying a Single Line of Text with Multiple Statements
2.3.2 Displaying Multiple Lines of Text with a Single Statement
2.4 Displaying Text in a Dialog Box
2.5 Another Java Application: Adding Integers
2.6 Memory Concepts
2.7 Arithmetic
2.8 Decision Making: Equality and Relational Operators
2.9 (Optional Case Study) Thinking About Objects: Examining the Problem Statement

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

2.1 Introduction

The Java language facilitates a disciplined approach to computer program design. We now introduce Java programming and present examples that illustrate several important features of Java. Each example is analyzed one line at a time. In this chapter and Chapter 3, we present two program types in Java—*applications* and *applets*. In Chapter 4 and Chapter 5, we present a detailed treatment of *program development* and *program control* in Java.

2.2 A First Program in Java: Printing a Line of Text

Java uses notations that may appear strange to nonprogrammers. We begin by considering a simple *application* that displays a line of text. An application is a program that executes using the **`java`** interpreter (discussed later in this section). The program and its output are shown in Fig. 2.1.

This program illustrates several important features of the Java language. We consider each line of the program in detail. Each program we present in this book has line numbers included for the reader's convenience; line numbers are not part of actual Java programs. Line 9 does the "real work" of the program, namely displaying the phrase **`Welcome to Java Programming!`** on the screen. But let us consider each line in order. Line 1,

```
// Fig. 2.1: Welcome1.java
```

begins with **`//`**, indicating that the remainder of the line is a *comment.* Programmers insert comments to *document* programs and improve program readability. Comments also help other people read and understand a program. Comments do not cause the computer to perform any action when the program is run. The Java compiler ignores comments. We begin every program with a comment indicating the figure number and file name (line 1).

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```
1  // Fig. 2.1: Welcome1.java
2  // A first program in Java.
3
4  public class Welcome1 {
5
6     // main method begins execution of Java application
7     public static void main( String args[] )
8     {
9        System.out.println( "Welcome to Java Programming!" );
10
11    }  // end method main
12
13 }  // end class Welcome1
```

```
Welcome to Java Programming!
```

Fig. 2.1 A first program in Java.

Good Programming Practice 2.1

Use comments to clarify difficult concepts used in a program.

A comment that begins with **//** is called a *single-line comment*, because the comment terminates at the end of the current line. A **//** comment can also begin in the middle of a line and continue until the end of that line.

Multiple-line comments can be written in two other forms. For example,

```
/* This is a multiple
   line comment. It can be
   split over many lines */
```

is a comment that can spread over several lines. This type of comment begins with delimiter **/*** and ends with delimiter ***/**; this type of comment may be called a *multiple-line comment*. All text between the delimiters of the comment is ignored by the compiler. A similar form of comment called a *documentation comment* is delimited by **/**** and ***/**.

Common Programming Error 2.1

Forgetting one of the delimiters of a multiple-line comment is a syntax error.

Java absorbed comments delimited with **/*** and ***/** from the C programming language and single-line comments delimited with **//** from the C++ programming language. Java programmers generally use C++-style single-line comments in preference to C-style comments. Throughout this book, we use C++-style single-line comments. The documentation comment syntax (**/**** and ***/**) is special to Java. It enables programmers to embed documentation for their programs directly in the programs. The ***javadoc*** utility program (provided by Sun Microsystems with the Java 2 Software Development Kit) reads those comments from the program and uses them to prepare your program's documentation. There are subtle issues to using **javadoc**-style comments properly. We do not use **javadoc**-style comments in the programs presented in this book. However, **javadoc**-style comments are explained thoroughly in Appendix F.

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Line 2,

```
// A first program in Java.
```

is a single-line comment that describes the purpose of the program.

Good Programming Practice 2.2

Every program should begin with a comment describing the purpose of the program.

Line 3 is simply a blank line. Programmers use blank lines and space characters to make programs easier to read. Together, blank lines, space characters and tab characters are known as *white space*. (Space characters and tabs are known specifically as *white-space characters*.) Such characters are ignored by the compiler. We discuss conventions for using white-space characters in this chapter and the next several chapters, as these spacing conventions are needed in may Java programs.

Good Programming Practice 2.3

Use blank lines, space characters and tab characters to enhance program readability.

Line 4,

```
public class Welcome1 {
```

begins a *class definition* for class **Welcome1**. Every program in Java consists of at least one class definition that is defined by you—the programmer. These classes are known as *programmer-defined classes*, or *user-defined classes*. The ***class*** *keyword* introduces a class definition in Java and is immediately followed by the *class name* (**Welcome1** in this program). Keywords (or *reserved words*) are reserved for use by Java (we discuss the various keywords throughout the text) and are always spelled with all lowercase letters. The complete list of Java keywords is shown in Fig. 4.2.

By convention, all class names in Java begin with a capital letter and have a capital letter for every word in the class name (e.g., **SampleClassName**). The name of the class is called an *identifier*. An identifier is a series of characters consisting of letters, digits, underscores (_) and dollar signs (**$**) that does not begin with a digit and does not contain spaces. Some valid identifiers are **Welcome1**, **$value**, **_value**, **m_inputField1** and **button7**. The name **7button** is not a valid identifier, because it begins with a digit, and the name **input field** is not a valid identifier, because it contains a space. Java is *case sensitive*—i.e., uppercase and lowercase letters are different, so **a1** and **A1** are different identifiers.

Common Programming Error 2.2

Java is case sensitive. Not using the proper uppercase and lowercase letters for an identifier is normally a syntax error.

Good Programming Practice 2.4

By convention, you should always begin a class name with a capital letter.

Good Programming Practice 2.5

When reading a Java program, look for identifiers that start with capital letters. These identifiers normally represent Java classes.

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Software Engineering Observation 2.1

*Avoid using identifiers that contain dollar signs (**$**), as the compiler often uses dollar signs to create identifier names.*

In Chapter 2 through Chapter 7, every class we define begins with the ***public*** *keyword*. For now, we will simply require this keyword. The **public** keyword is discussed in detail in Chapter 8. Also in that chapter, we discuss classes that do not begin with keyword **public**. [*Note*: Several times early in this text, we ask you to mimic certain Java features we introduce as you write your own Java programs. We specifically do this when it is not yet important for you to know all of the details of a feature in order for you to use that feature in Java. All programmers initially learn how to program by mimicking what other programmers have done before them. For each detail we ask you to mimic, we indicate where the full discussion will be presented later in the text.]

When you save your **public** class definition in a file, the file name must be the class name followed by the "**.java**" file-name extension. For our application, the file name is **Welcome1.java**. All Java class definitions are stored in files ending with the file-name extension "**.java**."

Common Programming Error 2.3

*It is an error for a **public** class if the file name is not identical to the class name (plus the **.java** extension) in terms of both spelling and capitalization. Therefore, it is also an error for a file to contain two or more **public** classes.*

Common Programming Error 2.4

*It is an error not to end a file name with the **.java** extension for a file containing an application's class definition. If the extension is missing, the Java compiler will not be able to compile the class definition.*

A *left brace* (at the end of line 4), **{**, begins the *body* of every class definition. A corresponding *right brace* (in line 13 in this program), **}**, must end each class definition. Notice that lines 6–11 are indented. This indentation is one of the spacing conventions mentioned earlier. We define each spacing convention as a *Good Programming Practice*.

Good Programming Practice 2.6

*Whenever you type an opening left brace, **{**, in your program, immediately type the closing right brace, **}**, then reposition the cursor between the braces to begin typing the body. This practice helps prevent errors due to missing braces.*

Good Programming Practice 2.7

*Indent the entire body of each class definition one "level" of indentation between the left brace, **{**, and the right brace, **}**, that define the body of the class. This format emphasizes the structure of the class definition and helps make the class definition easier to read.*

Good Programming Practice 2.8

Set a convention for the indent size you prefer, and then uniformly apply that convention. The Tab *key may be used to create indents, but tab stops may vary between editors. We recommend using three spaces to form a level of indent.*

Common Programming Error 2.5

If braces do not occur in matching pairs, the compiler indicates an error.

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Line 5 is a blank line, inserted for program readability. Line 6,

```
// main method begins execution of Java application
```

is a single-line comment indicating the purpose of lines 6–11 of the program.

Line 7,

```
public static void main( String args[] )
```

is a part of every Java application. Java applications begin executing at **main**. The parentheses after **main** indicate that **main** is a program building block called a *method*. Java class definitions normally contain one or more methods. For a Java application class, exactly one of those methods must be called **main** and must be defined as shown on line 7; otherwise, the **java** interpreter will not execute the application. Methods are able to perform tasks and return information when they complete their tasks. The ***void*** keyword indicates that this method will perform a task (displaying a line of text, in this program), but will not return any information when it completes its task. Later, we will see that many methods return information when they complete their task. Methods are explained in detail in Chapter 6. For now, simply mimic **main**'s first line in your Java applications.

The left brace, **{**, on line 8 begins the *body of the method definition*. A corresponding right brace, **}**, must end the method definition's body (line 11 of the program). Notice that the line in the body of the method is indented between the braces.

Good Programming Practice 2.9

*Indent the entire body of each method definition one "level" of indentation between the left brace, **{**, and the right brace, **}**, that define the body of the method. This format makes the structure of the method stand out and helps make the method definition easier to read.*

Line 9,

```
System.out.println( "Welcome to Java Programming!" );
```

instructs the computer to perform an *action*, namely to print the *string* of characters contained between the double quotation marks. A string is sometimes called a *character string*, a *message* or a *string literal*. We refer to characters between double quotation marks generically as *strings*. White-space characters in strings are not ignored by the compiler.

System.out is known as the *standard output object*. **System.out** allows Java applications to display strings and other types of information in the *command window* from which the Java application executes. In Microsoft Windows 95/98/ME, the command window is the *MS-DOS prompt*. In Microsoft Windows NT/2000, the command window is the *Command Prompt* (***cmd.exe***). In UNIX, the command window is normally called a *command window*, a *command tool*, a *shell tool* or a *shell*. On computers running an operating system that does not have a command window (such as a Macintosh), the **java** interpreter normally displays a window containing the information the program displays.

Method ***System.out.println*** *displays* (or *prints*) *a line* of text in the command window. When **System.out.println** completes its task, it automatically positions the *output cursor* (the location where the next character will be displayed) to the beginning of the next line in the command window. (This move of the cursor is similar to you pressing the *Enter* key when typing in a text editor—the cursor appears at the beginning of the next line in your file.)

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The entire line, including **`System.out.println`**, its *argument* in the parentheses (the string) and the *semicolon* (**`;`**), is a *statement*. Every statement must end with a semicolon (also known as the *statement terminator*). When the statement on line 9 of our program executes, it displays the message **`Welcome to Java Programming!`** in the command window.

Common Programming Error 2.6

Omitting the semicolon at the end of a statement is a syntax error. A syntax error *occurs when the compiler cannot recognize a statement. The compiler normally issues an error message to help the programmer identify and fix the incorrect statement. Syntax errors are violations of the language rules. Syntax errors are also called* compile errors, compile-time errors *or* compilation errors, *because the compiler detects them during the compilation phase. You will be unable to execute your program until you correct all of the syntax errors in it.*

Testing and Debugging Tip 2.1

When the compiler reports a syntax error, the error may not be on the line number indicated by the error message. First, check the line for which the error was reported. If that line does not contain syntax errors, check the preceding several lines in the program.

Some programmers find it difficult when reading and/or writing a program to match the left and right braces (**`{`** and **`}`**) that delimit the body of a class definition or a method definition. For this reason, some programmers prefer to include a single-line comment after a closing right brace (**`}`**) that ends a method definition and after a closing right brace that ends a class definition. For example, line 11,

```
} // end method main
```

specifies the closing right brace (**`}`**) of method **`main`**, and line 13,

```
} // end class Welcome1
```

specifies the closing right brace (**`}`**) of class **`Welcome1`**. Each comment indicates the method or class that the right brace terminates. We use such comments through Chapter 6 to help beginning programmers determine where each program component terminates. After Chapter 6, we use such comments when pairs of braces contain many statements, which makes the closing braces difficult to identify.

Good Programming Practice 2.10

*Some programmers prefer to follow the closing right brace (**`}`**) of a method body or class definition with a single-line comment indicating the method or class definition to which the brace belongs. This comment improves program readability.*

2.2.1 Compiling and Executing your First Java Application

We are now ready to compile and execute our program. To compile the program, we open a command window, change to the directory where the program is stored and type

```
javac Welcome1.java
```

If the program contains no syntax errors, the preceding command creates a new file called **`Welcome1.class`** containing the Java bytecodes that represent our application. These bytecodes will be interpreted by the **`java`** interpreter when we tell it to execute the program, as shown in the Microsoft Windows 2000 **Command Prompt** of Fig. 2.2.

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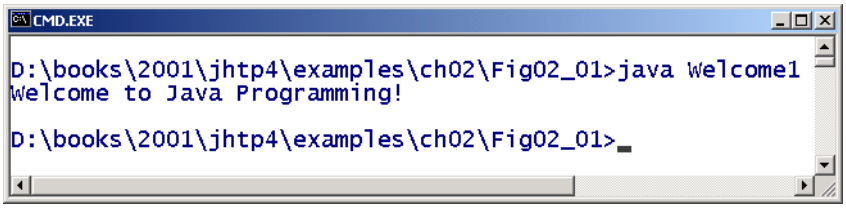

Fig. 2.2 Executing **`Welcome1`** in a Microsoft Windows 2000 **Command Prompt**.

In the command prompt of Figure 2.2, we typed

```
java Welcome1
```

to launch the **`java`** interpreter and indicate that it should load the "**`.class`**" file for class **`Welcome1`**. Note that the "**`.class`**" file-name extension is omitted from the preceding command; otherwise the interpreter will not execute the program. The interpreter automatically calls method **`main`**. Next, the statement on line 7 of **`main`** displays "**`Welcome to Java Programming!`**"

Testing and Debugging Tip 2.2

The Java compiler generates syntax error messages when the syntax of a program is incorrect. When you are learning how to program, sometimes it is helpful to "break" a working program so you can see the error messages produced by the compiler. Then, when you encounter that error message again, you will have an idea of the error's cause. Try removing a semicolon or curly brace from the program of Fig. 2.1, then recompile the program to see the error messages generated by the omission.

2.3 Modifying Our First Java Program

This section continues our introduction to Java programming with two examples that modify the example in Fig. 2.1 to print text on one line by using multiple statements and to print text on several lines by using a single statement.

2.3.1 Displaying a Single Line of Text with Multiple Statements

`Welcome to Java Programming!` can be displayed using several methods. Class **`Welcome2`**, shown in Fig. 2.3, uses two statements to produce the same output as that shown in Fig. 2.1.

Most of the program is identical to that of Fig. 2.1, so we discuss only the changes here. Line 2,

```
// Printing a line of text with multiple statements.
```

is a single-line comment stating the purpose of this program. Line 4 begins the definition of class **`Welcome2`**.

Lines 9–10 of method **`main`**,

```
System.out.print( "Welcome to " );
System.out.println( "Java Programming!" );
```

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```
1  // Fig. 2.3: Welcome2.java
2  // Printing a line of text with multiple statements.
3
4  public class Welcome2 {
5
6     // main method begins execution of Java application
7     public static void main( String args[] )
8     {
9        System.out.print( "Welcome to " );
10       System.out.println( "Java Programming!" );
11
12    }  // end method main
13
14 }  // end class Welcome2
```

```
Welcome to Java Programming
```

Fig. 2.3 Printing a line of text with multiple statements.

display one line of text in the command window. The first statement uses **`System.out`**'s method **`print`** to display a string. The difference between **`print`** and **`println`** is that, after displaying its argument, **`print`** does not position the output cursor at the beginning of the next line in the command window; the next character the program displays in the command window will appear immediately after the last character that **`print`** displays. Thus, line 10 positions the first character in its argument, "**`J`**," immediately after the last character that line 9 displays (the space character at the end of the string on line 9). Each **`print`** or **`println`** statement resumes displaying characters from where the last **`print`** or **`println`** statement stopped displaying characters.

2.3.2 Displaying Multiple Lines of Text with a Single Statement

A single statement can display multiple lines by using *newline characters*. Newline characters are "special characters" that indicate to **`System.out`**'s **`print`** and **`println`** methods when they should position the output cursor to the beginning of the next line in the command window. Figure 2.4 outputs four lines of text, using newline characters to determine when to begin each new line.

Most of the program is identical to those of Fig. 2.1 and Fig. 2.3, so we discuss only the changes here. Line 2,

```
// Printing multiple lines of text with a single statement.
```

is a single-line comment stating the purpose of this program. Line 4 begins the definition of class **`Welcome3`**.

Line 9,

```
System.out.println( "Welcome\nto\nJava\nProgramming!" );
```

displays four separate lines of text in the command window. Normally, the characters in a string are displayed exactly as they appear in the double quotes. Notice, however, that the

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two characters **** and **n** are not printed on the screen. The *backslash* (****) is called an *escape character*. It indicates that a "special character" is to be output. When a backslash appears in a string of characters, Java combines the next character with the backslash to form an *escape sequence*. The escape sequence **\n** is the *newline character*. When a newline character appears in a string being output with **System.out**, the newline character causes the screen's output cursor to move to the beginning of the next line in the command window. Some other common escape sequences are listed in Fig. 2.5.

```
1  // Fig. 2.4: Welcome3.java
2  // Printing multiple lines of text with a single statement.
3
4  public class Welcome3 {
5
6     // main method begins execution of Java application
7     public static void main( String args[] )
8     {
9        System.out.println( "Welcome\nto\nJava\nProgramming!" );
10
11    }  // end method main
12
13 }  // end class Welcome3
```

```
Welcome
to
Java
Programming!
```

Fig. 2.4 Printing multiple lines of text with a single statement.

Escape sequence	Description
\n	Newline. Position the screen cursor to the beginning of the next line.
\t	Horizontal tab. Move the screen cursor to the next tab stop.
\r	Carriage return. Position the screen cursor to the beginning of the current line; do not advance to the next line. Any characters output after the carriage return overwrite the characters previously output on that line.
****	Backslash. Used to print a backslash character.
\"	Double quote. Used to print a double-quote character. For example, **System.out.println("\"in quotes\"");** displays **"in quotes"**

Fig. 2.5 Some common escape sequences.

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2.4 Displaying Text in a Dialog Box

Although the first several programs presented in this chapter display output in the command window, many Java applications use windows or *dialog boxes* (also called *dialogs*) to display output. For example, World Wide Web browsers such as Netscape Navigator or Microsoft Internet Explorer display Web pages in their own windows. Email programs typically allow you to type and read messages in a window provided by the email program. Typically, dialog boxes are windows in which programs display important messages to the user of the program. Java's class **`JOptionPane`** provides prepackaged dialog boxes that enable programs to display messages to users. Figure 2.6 displays the same string as in Fig. 2.4 in a predefined dialog box known as a *message dialog*.

One of the great strengths of Java is its rich set of predefined classes that programmers can reuse rather than "reinventing the wheel." We use many of these classes throughout the book. Java's numerous predefined classes are grouped into categories of related classes called *packages*. The packages are referred to collectively as the *Java class library*, or the *Java applications programming interface* (*Java API*). The packages of the Java API are split into *core packages* and *extension packages*. The names of the packages begin with either "**`java`**" (core packages) or "**`javax`**" (extension packages). Many of the core and extension packages are included as part of the Java 2 Software Development Kit. We overview these included packages in Chapter 6. As Java continues to evolve, new packages are developed as extension packages. These extensions often can be downloaded from **`java.sun.com`** and used to enhance Java's capabilities. In this example, we use class **`JOptionPane`**, which Java defines for us in package **`javax.swing`**.

Line 4,

```
// Java extension packages
```

is a single-line comment indicating the section of the program in which we specify **`import`** statements for classes in Java's extension packages. In every program that specifies **`import`** statements, we separate the import statements into the following groups: Java core packages (for package names starting with **`java`**), Java extension packages (for package names starting with **`javax`**) and Deitel packages (for our own packages defined later in the book).

Line 5,

```
import javax.swing.JOptionPane;  // import class JOptionPane
```

is an **`import`** statement. The compiler uses **`import`** statements to identify and load classes used in a Java program. When you use classes from the Java API, the compiler attempts to ensure that you use them correctly. The **`import`** statements help the compiler locate the classes you intend to use. For each new class we use from the Java API, we indicate the package in which you can find that class. This package information is important. It helps you locate descriptions of each package and class in the *Java API documentation*. A Web-based version of this documentation can be found at

```
java.sun.com/j2se/1.3/docs/api/index.html
```

Also, you can download this documentation to your own computer from

```
java.sun.com/j2se/1.3/docs.html
```

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```
1  // Fig. 2.6: Welcome4.java
2  // Printing multiple lines in a dialog box
3
4  // Java extension packages
5  import javax.swing.JOptionPane;  // import class JOptionPane
6
7  public class Welcome4 {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       JOptionPane.showMessageDialog(
13          null, "Welcome\nto\nJava\nProgramming!" );
14
15       System.exit( 0 );  // terminate application
16
17    }  // end method main
18
19 }  // end class Welcome4
```

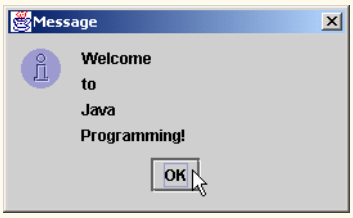

Fig. 2.6 Displaying multiple lines in a dialog box.

We will provide an overview of the use of this documentation with the downloads and resources for *Java How to Program, Fourth Edition* on our Web site, **www.deitel.com**. Packages are discussed in detail in Chapter 8, Object-Based Programming.

Common Programming Error 2.7

All ***import*** *statements must appear before the class definition. Placing an* ***import*** *statement inside a class definition's body or after a class definition is a syntax error.*

Line 5 tells the compiler to load the ***JOptionPane*** class from the ***javax.swing*** package. This package contains many classes that help Java programmers define *graphical user interfaces* (*GUIs*) for their application. *GUI components* facilitate data entry by the user of your program and formatting or presentation of data outputs to the user of your program. For example, Fig. 2.7 contains a Netscape Navigator window. In the window, there is a bar containing *menus* (**File**, **Edit**, **View**, etc.), called a *menu bar*. Below the menu bar is a set of *buttons* that each have a defined task in Netscape Navigator. Below the buttons there is a *text field* in which the user can type the name of the World Wide Web site to visit. The menus, buttons and text fields are part of Netscape Navigator's GUI. They enable you to interact with the Navigator program. Java contains classes that implement the GUI components described here and others that will be described in Chapter 12, Basic Graphical User Interface Components, and Chapter 13, Advanced Graphical User Interface Components.

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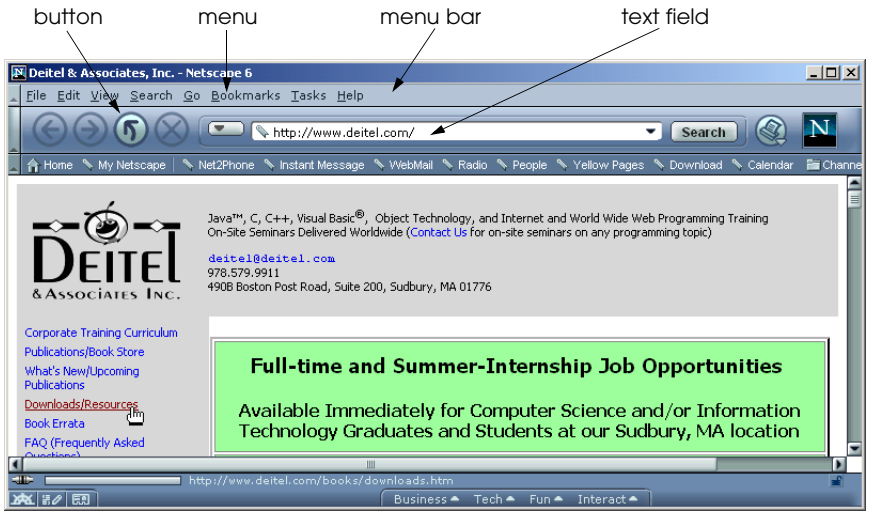

Fig. 2.7 A sample Netscape Navigator window with GUI components.

In method **`main`** of Fig. 2.6, lines 12–13,

```
JOptionPane.showMessageDialog(
   null, "Welcome\nto\nJava\nProgramming!" );
```

indicate a call to method ***`showMessageDialog`*** of class **`JOptionPane`**. The method requires two arguments. When a method requires multiple arguments, the arguments are separated with *commas* (**`,`**). Until we discuss **`JOptionPane`** in detail in Chapter 13, the first argument will always be the keyword ***`null`***. The second argument is the string to display. The first argument helps the Java application determine where to position the dialog box. When the first argument is **`null`**, the dialog box appears in the center of the computer screen. Most applications you use on your computer execute in their own window (e.g., email programs, Web browsers and word processors). When such an application displays a dialog box, it normally appears in the center of the application window, which is not necessarily the center of the screen. Later in this book, you will see more elaborate applications in which the first argument to method **`showMessageDialog`** will cause the dialog box to appear in the center of the application window, rather than the center of the screen.

Good Programming Practice 2.11

Place a space after each comma (`,`) in an argument list, to make programs more readable.

Method **`JOptionPane.showMessageDialog`** is a special method of class **`JOptionPane`** called a ***`static`*** *method*. Such methods are always called by using their class name followed by a dot operator (**`.`**) and the method name, as in

ClassName`.`*methodName*`(` *arguments* `)`

Many of the predefined methods we introduce early in this book are **`static`** methods. We ask you to mimic this syntax for calling **`static`** methods until we discuss them in detail in Chapter 8, Object-Based Programming.

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Executing the statement at lines 12–13 displays the dialog box in Fig. 2.8. The *title bar* of the dialog contains the string **Message**, to indicate that the dialog is presenting a message to the user. The dialog box automatically includes an **OK** button that allows the user to *dismiss* (*hide*) *the dialog* by pressing the button. This is accomplished by positioning the *mouse cursor* (also called the *mouse pointer*) over the **OK** button and clicking the left mouse button.

Remember that all statements in Java end with a semicolon (`;`). Therefore, lines 12–13 represent one statement. Java allows large statements to be split over many lines. However, you cannot split a statement in the middle of an identifier or in the middle of a string.

Common Programming Error 2.8

Splitting a statement in the middle of an identifier or a string is a syntax error.

Line 15,

```
System.exit( 0 );   // terminate application
```

uses **`static`** method ***`exit`*** of class **`System`** to terminate the application. In any application that displays a graphical user interface, this line is required in order to terminate the application. Notice once again the syntax used to call the method—the class name (**`System`**), a dot (**`.`**) and the method name (**`exit`**). Remember that identifiers starting with capital letters normally represent class names. So, you can assume that **`System`** is a class. Class **`System`** is part of the package ***`java.lang`***. Notice that class **`System`** is not imported with an **`import`** statement at the beginning of the program. By default, package **`java.lang`** is imported in every Java program. Package **`java.lang`** is the only package in the Java API for which you are not required to provide an **`import`** statement.

The argument **`0`** to method **`exit`** indicates that the application has terminated successfully. (A nonzero value normally indicates that an error has occurred.) This value is passed to the command window that executed the program. The argument is useful if the program is executed from a *batch file* (on Windows 95/98/ME/NT/2000 systems) or a *shell script* (on UNIX/Linux systems). Batch files and shell scripts often execute several programs in sequence. When the first program ends, the next program begins execution automatically. It is possible to use the argument to method **`exit`** in a batch file or shell script to determine whether other programs should execute. For more information on batch files or shell scripts, see your operating system's documentation.

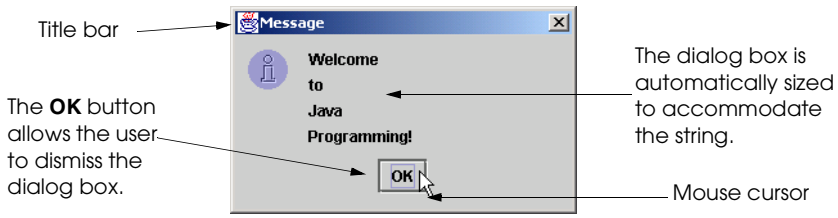

Fig. 2.8 Message dialog box.

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Common Programming Error 2.9

Forgetting to call **`System.exit`** *in an application that displays a graphical user interface prevents the program from terminating properly. This omission normally results in the command window preventing you from typing any other commands. Chapter 14 discusses in more detail the reason that* **`System.exit`** *is required in GUI-based applications.*

2.5 Another Java Application: Adding Integers

Our next application inputs two *integers* (whole numbers, like –22, 7 and 1024) typed by a user at the keyboard, computes the sum of the values and displays the result. This program uses another predefined dialog box from class **`JOptionPane`** called an *input dialog* that allows the user to input a value for use in the program. The program also uses a message dialog to display the sum of the integers. Figure 2.9 shows the application and sample screen captures.

```
1  // Fig. 2.9: Addition.java
2  // An addition program.
3
4  // Java extension packages
5  import javax.swing.JOptionPane;  // import class JOptionPane
6
7  public class Addition {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       String firstNumber;   // first string entered by user
13       String secondNumber;  // second string entered by user
14       int number1;          // first number to add
15       int number2;          // second number to add
16       int sum;              // sum of number1 and number2
17
18       // read in first number from user as a String
19       firstNumber =
20          JOptionPane.showInputDialog( "Enter first integer" );
21
22       // read in second number from user as a String
23       secondNumber =
24          JOptionPane.showInputDialog( "Enter second integer" );
25
26       // convert numbers from type String to type int
27       number1 = Integer.parseInt( firstNumber );
28       number2 = Integer.parseInt( secondNumber );
29
30       // add the numbers
31       sum = number1 + number2;
32
33       // display the results
34       JOptionPane.showMessageDialog(
35          null, "The sum is " + sum, "Results",
36          JOptionPane.PLAIN_MESSAGE );
```

Fig. 2.9 An addition program "in action" (part 1 of 2).

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```
37
38          System.exit( 0 );    // terminate application
39
40       }  // end method main
41
42    }  // end class Addition
```

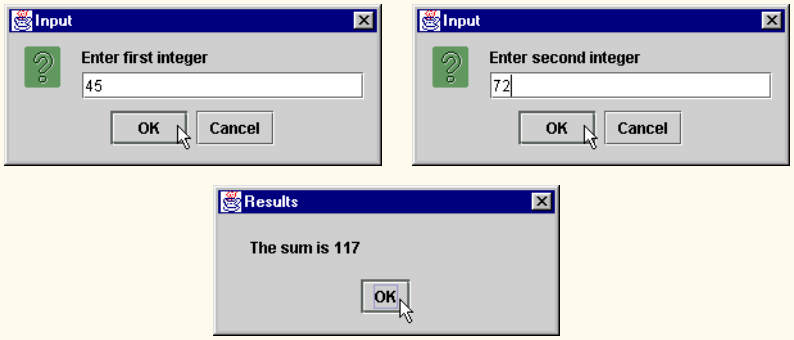

Fig. 2.9 An addition program "in action" (part 2 of 2).

Lines 1 and 2,

```
// Fig. 2.9: Addition.java
// An addition program.
```

are single-line comments stating the figure number, file name and purpose of the program.

Line 4,

```
// Java extension packages
```

is a single-line comment specifying that the next line imports a class from the Java extension packages.

Line 5,

```
import javax.swing.JOptionPane;  // import class JOptionPane
```

indicates that the compiler should load class **JOptionPane** for use in this application.

As stated earlier, every Java program consists of at least one class definition. Line 7,

```
public class Addition {
```

begins the definition of class **Addition**. The file name for this **public** class must be **Addition.java**.

Remember that all class definitions start with an opening left brace (at the end of line 7), **{**, and end with a closing right brace, **}** (in line 42).

As stated earlier, every application begins execution with method **main** (lines 10–40). The left brace (line 11) marks the beginning of **main**'s body and the corresponding right brace (line 36) marks the end of **main**'s body.

Lines 12–13,

```
String firstNumber;    // first string entered by user
String secondNumber;   // second string entered by user
```

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are *declarations*. The words **firstNumber** and **secondNumber** are the names of *variables*. A variable is a location in the computer's memory where a value can be stored for use by a program. All variables must be declared with a name and a data type before they can be used in a program. This declaration specifies that the variables **firstNumber** and **secondNumber** are data of type ***String*** (located in package **java.lang**), which means that the variables will hold strings. A variable name can be any valid identifier. Like statements, declarations end with a semicolon (**;**). Notice the single-line comments at the end of each line. This use and placement of the comments is a common practice used by programmers to indicate the purpose of each variable in the program.

Good Programming Practice 2.12

Choosing meaningful variable names helps a program to be self-documenting *(i.e., it becomes easier to understand the program simply by reading it rather than by reading manuals or viewing an excessive number of comments).*

Good Programming Practice 2.13

By convention, variable-name identifiers begin with a lowercase letter. As with class names, every word in the name after the first word should begin with a capital letter. For example, identifier ***firstNumber*** *has a capital* ***N*** *in its second word,* ***Number****.*

Good Programming Practice 2.14

Some programmers prefer to declare each variable on a separate line. This format allows for easy insertion of a descriptive comment next to each declaration.

Software Engineering Observation 2.2

Java automatically imports classes from package ***java.lang****, such as class* ***String****. Therefore,* ***import*** *statements are not required for classes in package* ***java.lang****.*

Declarations can be split over several lines, with each variable in the declaration separated by a comma (i.e., a *comma-separated list* of variable names). Several variables of the same type may be declared in one declaration or in multiple declarations. Lines 12–13 can also be written as follows:

```
String firstNumber,    // first string entered by user
       secondNumber;   // second string entered by user
```

Lines 14–16,

```
int number1;           // first number to add
int number2;           // second number to add
int sum;               // sum of number1 and number2
```

declare that variables **number1**, **number2** and **sum** are data of type ***int***, which means that these variables will hold *integer* values (whole numbers such as 7, –11, 0 and 31,914). We will soon discuss the data types **float** and **double**, for specifying real numbers (numbers with decimal points, such as 3.4, 0.0 and –11.19), and variables of type **char**, for specifying character data. A **char** variable may hold only a single lowercase letter, a single uppercase letter, a single digit or a single special character (such as **x**, **$**, **7** and *****) and escape sequences (such as the newline character, **\n**). Java is capable of representing characters from many other spoken languages. Types such as **int**, **double** and **char** are often called *primitive data types,* or *built-in data types*. Primitive-type names are keywords;

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thus, they must appear in all lowercase letters. Chapter 4 summarizes the eight primitive types (**boolean**, **char**, **byte**, **short**, **int**, **long**, **float** and **double**).

Line 18 is a single-line comment indicating that the next statement reads the first number from the user. Lines 19–20,

```
firstNumber =
   JOptionPane.showInputDialog( "Enter first integer" );
```

reads from the user a **String** representing the first of the two integers to add. Method **JOptionPane.showInputDialog** displays the input dialog in Fig. 2.10.

The argument to **showInputDialog** indicates what the user should type in the text field. This message is called a *prompt*, because it directs the user to take a specific action. The user types characters in the text field, and then clicks the **OK** button or presses the *Enter* key to return the string to the program. (If you type and nothing appears in the text field, position the mouse pointer in the text field and click the left mouse button to activate the text field.) Unfortunately, Java does not provide a simple form of input that is analogous to displaying output in the command window with **System.out**'s method **print** and **println**. For this reason, we normally receive input from a user through a GUI component (an input dialog box in this program).

Technically, the user can type anything in the text field of the input. Our program assumes that the user follows directions and enters a valid integer value. In this program, if the user either types a noninteger value or clicks the **Cancel** button in the input dialog, a runtime logic error will occur. Chapter 14, Exception Handling, discusses how to make your programs more robust by enabling them to handle such errors. This is also known as making your program *fault tolerant*.

The result of **JOptionPane** method **showInputDialog** (a **String** containing the characters typed by the user) is given to variable **firstNumber** by using the *assignment operator*, **=**. The statement (lines 19–20) is read as "**firstNumber** *gets* the value of **JOptionPane.showInputDialog("Enter first integer")**." The **=** operator is called a *binary operator*, because it has two *operands*: **firstNumber** and the result of the expression **JOptionPane.showInputDialog("Enter first integer")**. This whole statement is called an *assignment statement*, because it assigns a value to a variable. The expression to the right side of the assignment operator, **=**, is always evaluated first. In this case, the program calls method **showInputDialog**, and the value input by the user is assigned to **firstNumber**.

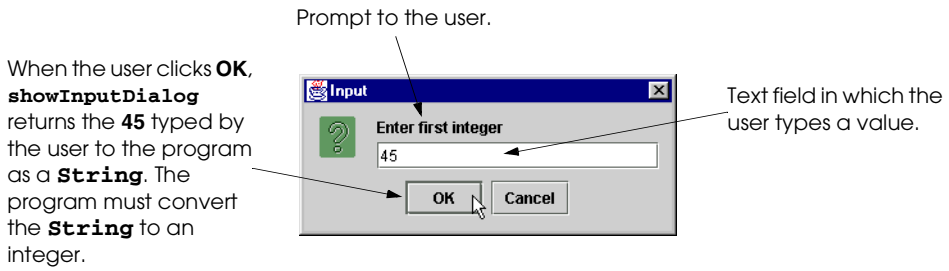

Fig. 2.10 Input dialog box.

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Line 22 is a single-line comment indicating that the next statement reads the second number from the user.

Lines 23–24,

```
secondNumber =
   JOptionPane.showInputDialog( "Enter second integer" );
```

display an input dialog in which the user types a **String** representing the second of the two integers to add.

Lines 27–28,

```
number1 = Integer.parseInt( firstNumber );
number2 = Integer.parseInt( secondNumber );
```

convert the two **String**s input by the user to **int** values that the program can use in a calculation. Method ***Integer.parseInt*** (a **static** method of class **Integer**) converts its **String** argument to an integer. Class **Integer** is defined in package **java.lang**. Line 27 assigns the **int** (integer) value that **Integer.parseInt** returns to variable **number1**. Line 28 assigns the **int** (integer) value that **Integer.parseInt** returns to variable **number2**.

Line 31,

```
sum = number1 + number2;
```

is an assignment statement that calculates the sum of the variables **number1** and **number2** and assigns the result to variable **sum** by using the assignment operator, **=**. The statement is read as, "**sum** *gets* the value of **number1 + number2**." Most calculations are performed in assignment statements. When the program encounters the addition operation, it uses the values stored in the variables **number1** and **number2** to perform the calculation. In the preceding statement, the addition operator is a binary operator: its two operands are **number1** and **number2**.

Good Programming Practice 2.15

Place spaces on either side of a binary operator. This format makes the operator stand out and makes the program more readable.

After the calculation has been performed, lines 34–36,

```
JOptionPane.showMessageDialog(
   null, "The sum is " + sum, "Results",
   JOptionPane.PLAIN_MESSAGE );
```

use method **JOptionPane.showMessageDialog** to display the result of the addition. This new version of **JOptionPane** method **showMessageDialog** requires four arguments. As in Fig. 2.6, the **null** first argument indicates that the message dialog will appear in the center of the screen. The second argument is the message to display. In this case, the second argument is the expression

```
"The sum is " + sum
```

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which uses the operator **+** to "add" a **String** (the literal **"The sum is "**) and the value of variable **sum** (the **int** variable containing the result of the addition on line 31). Java has a version of the **+** operator for *string concatenation* that concatenates a **String** and a value of another data type (including another **String**); the result of this operation is a new (and normally longer) **String**. If we assume that **sum** contains the integer value **117**, the expression evaluates as follows:

1. Java determines that the two operands of the **+** operator (the string **"The sum is "** and the integer **sum**) are of different types and one of them is a **String**.
2. Java converts **sum** to a **String**.
3. Java appends the **String** representation of **sum** to the end of **"The sum is "**, resulting in the **String "The sum is 117"**.

Method **showMessageDialog** displays the resulting **String** in the dialog box. Note that the automatic conversion of integer **sum** occurs only because the addition operation concatenates the **String** literal **"The sum is "** and **sum**. Also, note that the space between **is** and **117** is part of the string **"The sum is "**. String concatenation is discussed in detail in Chapter 10, "Strings and Characters."

Common Programming Error 2.10

Confusing the **+** *operator used for string concatenation with the* **+** *operator used for addition can lead to strange results. For example, assuming that integer variable* **y** *has the value* **5**, *the expression* **"y + 2 = " + y + 2** *results in the string* **"y + 2 = 52"**, *not* **"y + 2 = 7"**, *because first the value of* **y** *is concatenated with the string* **"y + 2 = "**, *and then the value* **2** *is concatenated with the new larger string* **"y + 2 = 5"**. *The expression* **"y + 2 = " + (y + 2)** *produces the desired result.*

The third and fourth arguments of method **showMessageDialog** in Fig. 2.9 represent the string that should appear in the dialog box's *title bar* and the *dialog box type*, respectively. The fourth argument—**JOptionPane.PLAIN_MESSAGE**—is a value indicating the type of message dialog to display. This type of message dialog does not display an icon to the left of the message. Figure 2.11 illustrates the second and third arguments and shows that there is no icon in the window.

The message dialog types are shown in Fig. 2.12. All message dialog types except **PLAIN_MESSAGE** dialogs display an icon to the user indicating the type of message.

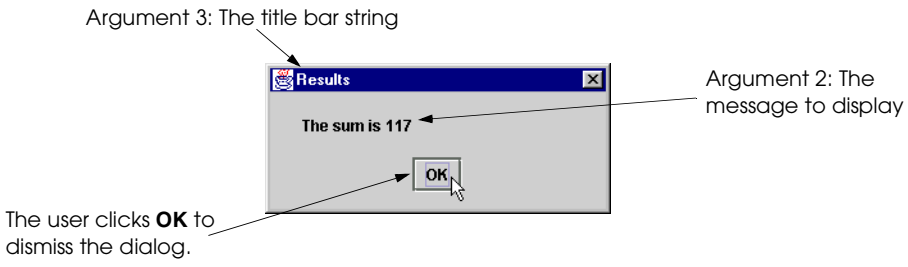

Fig. 2.11 Message dialog box customized with the four-argument version of method **showMessageDialog**.

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Message dialog type	Icon	Description
`JOptionPane.ERROR_MESSAGE`		Displays a dialog that indicates an error to the user.
`JOptionPane.INFORMATION_MESSAGE`		Displays a dialog with an informational message to the user. The user can simply dismiss the dialog.
`JOptionPane.WARNING_MESSAGE`		Displays a dialog that warns the user of a potential problem.
`JOptionPane.QUESTION_MESSAGE`		Displays a dialog that poses a question to the user. This dialog normally requires a response, such as clicking on a **Yes** or a **No** button.
`JOptionPane.PLAIN_MESSAGE`	no icon	Displays a dialog that simply contains a message, with no icon.

Fig. 2.12 `JOptionPane` constants for message dialogs.

2.6 Memory Concepts

Variable names such as **number1**, **number2** and **sum** actually correspond to *locations* in the computer's memory. Every variable has a *name,* a *type,* a *size* and a *value.*

In the addition program of Fig. 2.9, when the statement

```
number1 = Integer.parseInt( firstNumber );
```

executes, the string previously typed by the user in the input dialog and stored in **firstNumber** is converted to an **int** and placed into a memory location to which the name **number1** has been assigned by the compiler. Suppose that the user enters the string **45** as the value for **firstNumber**. The program converts **firstNumber** to an **int**, and the computer places that integer value, **45**, into location **number1**, as shown in Fig. 2.13.

Whenever a value is placed in a memory location, the value replaces the previous value in that location. The previous value is destroyed (i.e., lost).

When the statement

```
number2 = Integer.parseInt( secondNumber );
```

executes, suppose that the user enters the string **72** as the value for **secondNumber**. The program converts **secondNumber** to an **int**, and the computer places that integer value, **72**, into location **number2**. The memory appears as shown in Fig. 2.14.

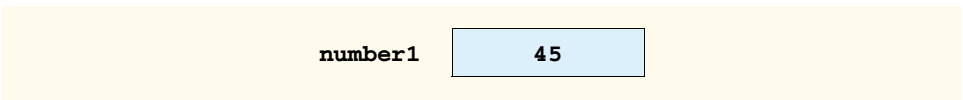

Fig. 2.13 Memory location showing the name and value of variable **number1**.

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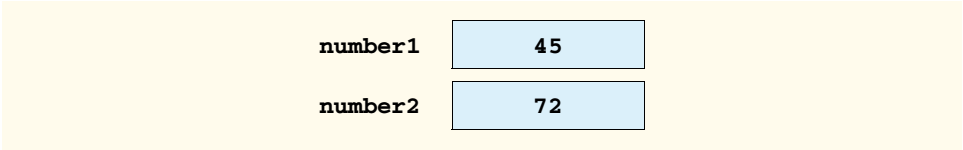

Fig. 2.14 Memory locations after storing values for **number1** and **number2**.

After the program of Fig. 2.9 obtains values for **number1** and **number2**, it adds the values and places the sum into variable **sum**. The statement

```
sum = number1 + number2;
```

performs the addition and also replaces **sum**'s previous value. After **sum** has been calculated, memory appears as shown in Fig. 2.15. Note that the values of **number1** and **number2** appear exactly as they did before they were used in the calculation of **sum**. These values were used, but not destroyed, as the computer performed the calculation. Thus, when a value is read from a memory location, the process is nondestructive.

2.7 Arithmetic

Most programs perform arithmetic calculations. The *arithmetic operators* are summarized in Fig. 2.16. Note the use of various special symbols not used in algebra. The *asterisk* (*****) indicates multiplication, and the *percent sign* (**%**) is the *modulus operator*, which is discussed shortly. The arithmetic operators in Fig. 2.16 are binary operators, because they each operate on two operands. For example, the expression **sum + value** contains the binary operator **+** and the two operands **sum** and **value**.

Integer division yields an integer quotient; for example, the expression **7 / 4** evaluates to **1**, and the expression **17 / 5** evaluates to **3**. Note that any fractional part in integer division is simply discarded (i.e., truncated)—no rounding occurs. Java provides the modulus operator, **%**, that yields the remainder after integer division. The expression **x % y** yields the remainder after **x** is divided by **y**. Thus, **7 % 4** yields **3**, and **17 % 5** yields **2**. This operator is most commonly used with integer operands, but also can be used with other arithmetic types. In later chapters, we consider many interesting applications of the modulus operator, such as determining if one number is a multiple of another. There is no arithmetic operator for exponentiation in Java. Chapter 5 shows how to perform exponentiation in Java. [*Note*: The modulus operator can be used with both integer and floating-point numbers.]

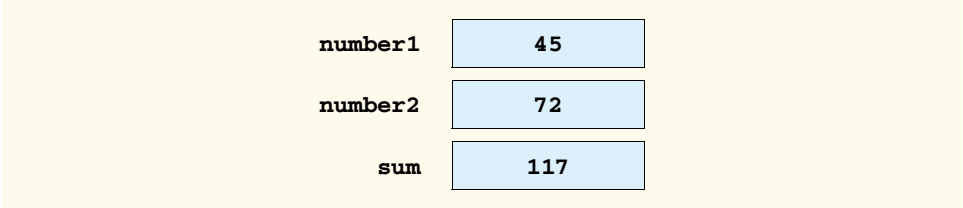

Fig. 2.15 Memory locations after calculating the **sum** of **number1** and **number2**.

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Java operation	Arithmetic operator	Algebraic expression	Java expression
Addition	`+`	$f + 7$	`f + 7`
Subtraction	`-`	$p - c$	`p - c`
Multiplication	`*`	bm	`b * m`
Division	`/`	x / y or $\frac{x}{y}$ or $x \div y$	`x / y`
Modulus	`%`	$r \bmod s$	`r % s`

Fig. 2.16 Arithmetic operators.

Arithmetic expressions in Java must be written in *straight-line form* to facilitate entering programs into the computer. Thus, expressions such as "**a** divided by **b**" must be written as **a / b**, so that all constants, variables and operators appear in a straight line. The following algebraic notation is generally not acceptable to compilers:

$$\frac{a}{b}$$

Parentheses are used in Java expressions in the same manner as in algebraic expressions. For example, to multiply **a** times the quantity **b + c**, we write

```
a * ( b + c )
```

Java applies the operators in arithmetic expressions in a precise sequence determined by the following *rules of operator precedence*, which are generally the same as those followed in algebra:

1. Operators in expressions contained within pairs of parentheses are evaluated first. Thus, *parentheses may be used to force the order of evaluation to occur in any sequence desired by the programmer.* Parentheses are at the highest level of precedence. In cases of *nested* or *embedded* parentheses, the operators in the innermost pair of parentheses are applied first.
2. Multiplication, division and modulus operations are applied next. If an expression contains several multiplication, division or modulus operations, the operators are applied from left to right. Multiplication, division and modulus operators have the same level of precedence.
3. Addition and subtraction operations are applied last. If an expression contains several addition and subtraction operations, the operators are applied from left to right. Addition and subtraction operators have the same level of precedence.

The rules of operator precedence enable Java to apply operators in the correct order. When we say that operators are applied from left to right, we are referring to the *associativity* of the operators. We will see that some operators associate from right to left. Figure 2.17 summarizes these rules of operator precedence. This table will be expanded as additional Java operators are introduced. A complete precedence chart is included in Appendix C.

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Operator(s)	Operation(s)	Order of evaluation (precedence)
`( )`	Parentheses	Evaluated first. If the parentheses are nested, the expression in the innermost pair is evaluated first. If there are several pairs of parentheses on the same level (i.e., not nested), they are evaluated left to right.
`*`, `/` and `%`	Multiplication Division Modulus	Evaluated second. If there are several of this type of operator, they are evaluated from left to right.
`+` or `-`	Addition Subtraction	Evaluated last. If there are several of this type of operator, they are evaluated from left to right.

Fig. 2.17 Precedence of arithmetic operators.

Now, let us consider several expressions in light of the rules of operator precedence. Each example lists an algebraic expression and its Java equivalent.

The following is an example of an arithmetic mean (average) of five terms:

Algebra: $m = \frac{a + b + c + d + e}{5}$

Java:
```
m = ( a + b + c + d + e ) / 5;
```

The parentheses are required, because division has higher precedence than that of addition. The entire quantity `( a + b + c + d + e )` is to be divided by `5`. If the parentheses are erroneously omitted, we obtain `a + b + c + d + e / 5`, which evaluates as

$$a + b + c + d + \frac{e}{5}$$

The following is an example of the equation of a straight line:

Algebra: $y = mx + b$

Java:
```
y = m * x + b;
```

No parentheses are required. The multiplication operator is applied first, because multiplication has a higher precedence than that of addition. The assignment occurs last, because it has a lower precedence than that of multiplication and division.

The following example contains modulus (`%`), multiplication, division, addition and subtraction operations:

Algebra: $z = pr\%q + w/x - y$

Java:
```
z = p * r % q + w / x - y;
```

6 1 2 4 3 5

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The circled numbers under the statement indicate the order in which Java applies the operators. The multiplication, modulus and division operations are evaluated first in left-to-right order (i.e., they associate from left to right), because they have higher precedence than that of addition and subtraction. The addition and subtraction operations are evaluated next. These operations are also applied from left to right.

Not all expressions with several pairs of parentheses contain nested parentheses. For example, the expression

```
a * ( b + c ) + c * ( d + e )
```

does not contain nested parentheses. Rather, these parentheses are on the same level.

To develop a better understanding of the rules of operator precedence, consider the evaluation of a second-degree polynomial ($y = ax^2 + bx + c$):

```
y  =  a  *  x  *  x  +  b  *  x  +  c;
      6     1     2     4     3     5
```

The circled numbers under the preceding statement indicate the order in which Java applies the operators. There is no arithmetic operator for exponentiation in Java; x^2 is represented as **`x * x`**.

Suppose that **`a`**, **`b`**, **`c`** and **`x`** are initialized as follows: **`a = 2`**, **`b = 3`**, **`c = 7`** and **`x = 5`**. Figure 2.18 illustrates the order in which the operators are applied in the preceding second-degree polynomial.

As in algebra, it is acceptable to place unnecessary parentheses in an expression to make the expression clearer. Such unnecessary parentheses are also called *redundant parentheses*. For example, the preceding assignment statement might be parenthesized as follows:

```
y = ( a * x * x ) + ( b * x ) + c;
```

Good Programming Practice 2.16

Using parentheses for complex arithmetic expressions, even when the parentheses are not necessary, can make the arithmetic expressions easier to read.

2.8 Decision Making: Equality and Relational Operators

This section introduces a simple version of Java's ***`if`*** *structure* that allows a program to make a decision based on the truth or falsity of some *condition*. If the condition is met (i.e., the condition is *true*), the statement in the body of the **`if`** structure is executed. If the condition is not met (i.e., the condition is *false*), the body statement does not execute. We will see an example shortly.

Conditions in **`if`** structures can be formed by using the *equality operators* and *relational operators* summarized in Fig. 2.19. The relational operators all have the same level of precedence and associate from left to right. The equality operators both have the same level of precedence, which is lower than the precedence of the relational operators. The equality operators also associate from left to right.

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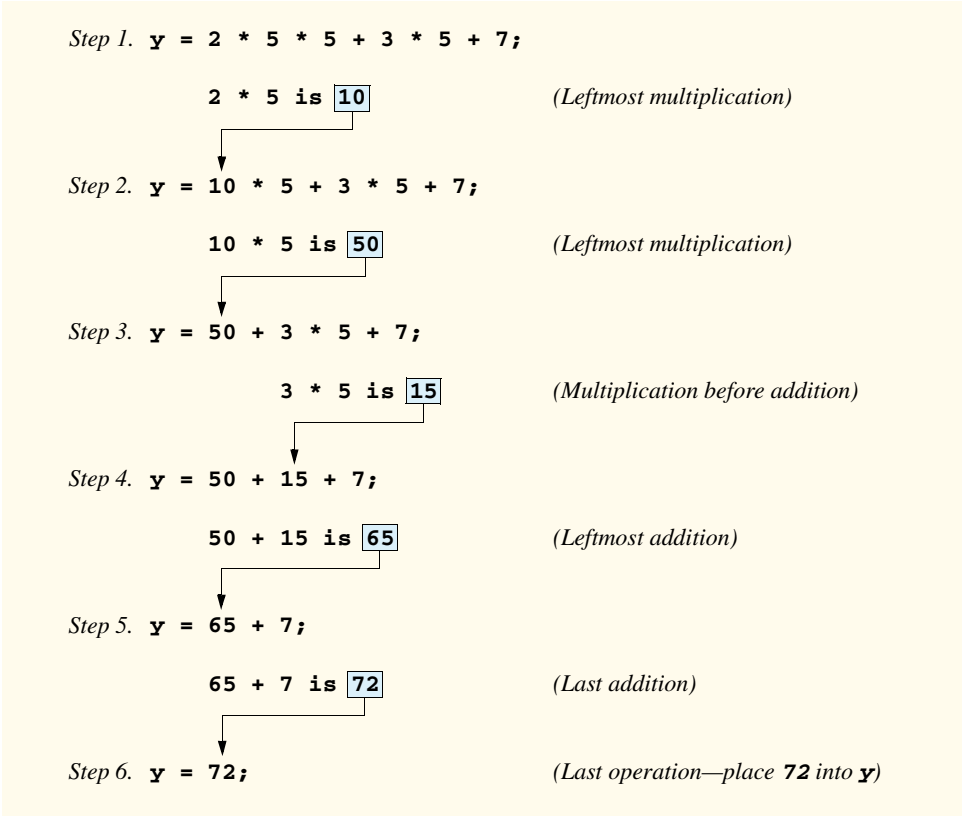

Fig. 2.18 Order in which a second-degree polynomial is evaluated.

Standard algebraic equality or relational operator	Java equality or relational operator	Example of Java condition	Meaning of Java condition
Equality operators			
=	`==`	`x == y`	`x` is equal to `y`
≠	`!=`	`x != y`	`x` is not equal to `y`
Relational operators			
>	`>`	`x > y`	`x` is greater than `y`
<	`<`	`x < y`	`x` is less than `y`
≥	`>=`	`x >= y`	`x` is greater than or equal to `y`
≤	`<=`	`x <= y`	`x` is less than or equal to `y`

Fig. 2.19 Equality and relational operators.

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Common Programming Error 2.11

It is a syntax error if the operators `==`, `!=`, `>=` *and* `<=` *contain spaces between their symbols, as in* `= =`, `! =`, `> =` *and* `< =`, *respectively.*

Common Programming Error 2.12

Reversing the operators `!=`, `>=` *and* `<=`, *as in* `=!`, `=>` *and* `=<`, *is a syntax error.*

Common Programming Error 2.13

Confusing the equality operator, `==`, *with the assignment operator,* `=`, *can be a logic error or a syntax error. The equality operator should be read as "is equal to," and the assignment operator should be read as "gets" or "gets the value of." Some people prefer to read the equality operator as "double equals" or "equals equals."*

The next example uses six **`if`** structures to compare two numbers input into text fields by the user. If the condition in any of these **`if`** statements is true, the assignment statement associated with that **`if`** structure executes. The user inputs two values through input dialogs. Next, the program converts the input values to integers and stores them in variables **`number1`** and **`number2`**. Then, the program compares the numbers and displays the results of the comparisons in an information dialog. The program and sample outputs are shown in Fig. 2.20.

```
1  // Fig. 2.20: Comparison.java
2  // Compare integers using if structures, relational operators
3  // and equality operators.
4
5  // Java extension packages
6  import javax.swing.JOptionPane;
7
8  public class Comparison {
9
10    // main method begins execution of Java application
11    public static void main( String args[] )
12    {
13       String firstNumber;    // first string entered by user
14       String secondNumber;   // second string entered by user
15       String result;         // a string containing the output
16       int number1;           // first number to compare
17       int number2;           // second number to compare
18
19       // read first number from user as a string
20       firstNumber =
21          JOptionPane.showInputDialog( "Enter first integer:" );
22
23       // read second number from user as a string
24       secondNumber =
25          JOptionPane.showInputDialog( "Enter second integer:" );
26
```

Fig. 2.20 Using equality and relational operators (part 1 of 3).

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```
27          // convert numbers from type String to type int
28          number1 = Integer.parseInt( firstNumber );
29          number2 = Integer.parseInt( secondNumber );
30
31          // initialize result to empty String
32          result = "";
33
34          if ( number1 == number2 )
35             result = number1 + " == " + number2;
36
37          if ( number1 != number2 )
38             result = number1 + " != " + number2;
39
40          if ( number1 < number2 )
41             result = result + "\n" + number1 + " < " + number2;
42
43          if ( number1 > number2 )
44             result = result + "\n" + number1 + " > " + number2;
45
46          if ( number1 <= number2 )
47             result = result + "\n" + number1 + " <= " + number2;
48
49          if ( number1 >= number2 )
50             result = result + "\n" + number1 + " >= " + number2;
51
52          // Display results
53          JOptionPane.showMessageDialog(
54             null, result, "Comparison Results",
55             JOptionPane.INFORMATION_MESSAGE );
56
57          System.exit( 0 );  // terminate application
58
59       }  // end method main
60
61    }  // end class Comparison
```

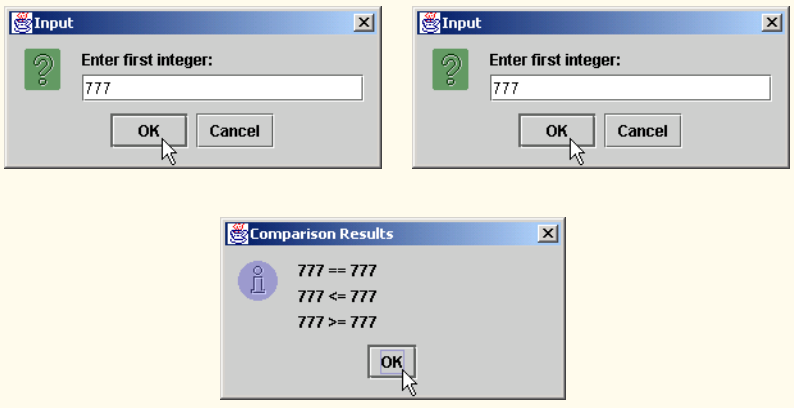

Fig. 2.20 Using equality and relational operators (part 2 of 3).

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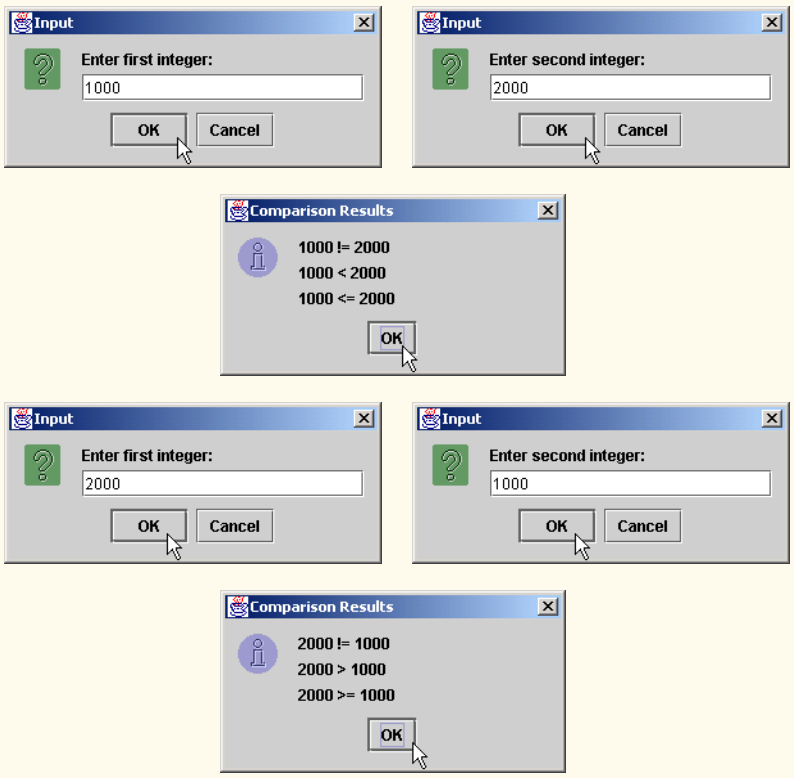

Fig. 2.20 Using equality and relational operators (part 3 of 3).

The definition of application class **`Comparison`** begins at line 8,

```
public class Comparison {
```

As discussed previously, method **`main`** (lines 11–59) begins the execution of every Java application.

Lines 13–17,

```
String firstNumber;    // first string entered by user
String secondNumber;   // second string entered by user
String result;         // a string containing the output
int number1;           // first number to compare
int number2;           // second number to compare
```

declare the variables used in method **`main`**. Note that there are three variables of type **`String`** and two variables of type **`int`**. Remember that variables of the same type may be declared in one declaration or in multiple declarations. If more than one name is declared in a declaration, the names are separated by commas (**`,`**), as in

```
String firstNumber, secondNumber, result;
```

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or as in

```
String firstNumber,
       secondNumber,
       result;
```

This is set of names known as a *comma-separated list*. Once again, notice the comment at the end of each declaration in lines 13–17, indicating the purpose of each variable in the program.

Lines 20–21,

```
firstNumber =
   JOptionPane.showInputDialog( "Enter first integer:" );
```

use **JOptionPane.showInputDialog** to allow the user to input the first integer value as a string and store it in **firstNumber**.

Lines 24–25,

```
secondNumber =
   JOptionPane.showInputDialog( "Enter second integer:" );
```

use **JOptionPane.showInputDialog** to allow the user to input the second integer value as a string and store it in **secondNumber**.

Lines 28–29,

```
number1 = Integer.parseInt( firstNumber );
number2 = Integer.parseInt( secondNumber );
```

convert each string input by the user in the input dialogs to type **int** and assign the values to int variables **number1** and **number2**.

Line 32,

```
result = "";
```

assigns to **result** the *empty string*—a string containing no characters. Every variable declared in a method (such as **main**) must be *initialized* (given a value) before it can be used in an expression. Because we do not yet know what the final **result** string will be, we assign to **result** the empty string as a temporary initial value.

Common Programming Error 2.14

Not initializing a variable defined in a method before that variable is used in the method's body is a syntax error.

Lines 34–35,

```
if ( number1 == number2 )
   result = result + number1 + " == " + number2;
```

define an ***if*** *structure* that compares the values of the variables **number1** and **number2** to determine if they are equal. The **if** structure always begins with keyword **if**, followed by a condition in parentheses. The **if** structure expects one statement in its body. The indentation shown here is not required, but it improves the readability of the program by emphasizing that the statement in line 35 is part of the **if** structure that begins on line 34.

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Good Programming Practice 2.17

Indent the statement i7n the body of an **`if`** *structure to make the body of the structure stand out and to enhance program readability.*

Good Programming Practice 2.18

Place only one statement per line in a program. This format enhances program readability

In the preceding **`if`** structure, if the values of variables **`number1`** and **`number2`** are equal, line 35 assigns to **`result`** the value of **`result + number1 + " == " + number2`**. As discussed in Fig. 2.9, the **`+`** operator in this expression performs string concatenation. For this discussion, we assume that each of the variables **`number1`** and **`number2`** has the value **`123`**. First, the expression converts **`number1`**'s value to a string and appends it to **`result`** (which currently contains the empty string) to produce the string **`"123"`**. Next, the expression appends **`" == "`** to **`"123"`** to produce the string **`"123 == "`**. Finally, the expression appends **`number2`** to **`"123 == "`** to produce the string **`"123 == 123"`**. The **`String result`** becomes longer as the program proceeds through the **`if`** structures and performs more concatenations. For example, given the value **`123`** for both **`number1`** and **`number2`** in this discussion, the **`if`** conditions at lines 46–47 (**`<=`**) and 49–50 (**`>=`**) are also true. So, the program displays the **`result`**

```
123 == 123
123 <= 123
123 >= 123
```

in a message dialog.

Common Programming Error 2.15

Replacing operator **`==`** *in the condition of an* **`if`** *structure, such as* **`if ( x == 1 )`***, with operator* **`=`***, as in* **`if ( x = 1 )`***, is a syntax error.*

Common Programming Error 2.16

Forgetting the left and right parentheses for the condition in an **`if`** *structure is a syntax error. The parentheses are required.*

Notice that there is no semicolon (**`;`**) at the end of the first line of each **`if`** structure. Such a semicolon would result in a logic error at execution time. For example,

```
if ( number1 == number2 );  // logic error
   result = result + number1 + " == " + number2;
```

would actually be interpreted by Java as

```
if ( number1 == number2 )
   ;

result = result + number1 + " == " + number2;
```

where the semicolon on the line by itself—called the *empty statement*—is the statement to execute if the condition in the **`if`** structure is true. When the empty statement executes, no task is performed in the program. The program then continues with the assignment statement, which executes regardless of whether the condition is true or false.

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Common Programming Error 2.17

Placing a semicolon immediately after the right parenthesis of the condition in an **`if`** *structure is normally a logic error. The semicolon will cause the body of the* **`if`** *structure to be empty, so the* **`if`** *structure itself will perform no action, regardless of whether its condition is true. Worse yet, the intended body statement of the* **`if`** *structure will now become a statement in sequence with the* **`if`** *structure and will always be executed.*

Notice the use of spacing in Fig. 2.20. Remember that white-space characters, such as tabs, newlines and spaces, are normally ignored by the compiler. So, statements may be split over several lines and may be spaced according to the programmer's preferences without affecting the meaning of a program. It is incorrect to split identifiers and string literals. Ideally, statements should be kept small, but it is not always possible to do so.

Good Programming Practice 2.19

A lengthy statement may be spread over several lines. If a single statement must be split across lines, choose breaking points that make sense, such as after a comma in a comma-separated list, or after an operator in a lengthy expression. If a statement is split across two or more lines, indent all subsequent lines until the end of the statement.

The chart in Fig. 2.21 shows the precedence of the operators introduced in this chapter. The operators are shown from top to bottom in decreasing order of precedence. Notice that all of these operators, with the exception of the assignment operator, **`=`**, associate from left to right. Addition is left associative, so an expression like **`x + y + z`** is evaluated as if it had been written as **`( x + y ) + z`**. The assignment operator, **`=`**, associates from right to left, so an expression like **`x = y = 0`** is evaluated as if it had been written as **`x = ( y = 0 )`**, which, as we will soon see, first assigns the value **`0`** to variable **`y`** and then assigns the result of that assignment, **`0`**, to **`x`**.

Good Programming Practice 2.20

Refer to the operator precedence chart (see the complete chart in Appendix C) when writing expressions containing many operators. Confirm that the operations in the expression are performed in the order you expect. If you are uncertain about the order of evaluation in a complex expression, use parentheses to force the order, exactly as you would do in algebraic expressions. Be sure to observe that some operators, such as assignment, **`=`***, associate from right to left rather than from left to right.*

Operators	Associativity	Type
`( )`	left to right	parentheses
`*  /  %`	left to right	multiplicative
`+  -`	left to right	additive
`<  <=  >  >=`	left to right	relational
`==  !=`	left to right	equality
`=`	right to left	assignment

Fig. 2.21 Precedence and associativity of the operators discussed so far.

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We have introduced many important features of Java in this chapter, including displaying data on the screen, inputting data from the keyboard, performing calculations and making decisions. We should note that these applications are meant to introduce the reader to basic programming concepts. As you will see in later chapters, more substantial Java applications contain just a few lines of code in method **`main`** that creates the objects that perform the work of the application. In Chapter 3, we demonstrate many similar techniques as we introduce Java applet programming. In Chapter 4, we build on the techniques of Chapter 2 and Chapter 3 as we introduce *structured programming*. You will become more familiar with indentation techniques. We will study how to specify and vary the order in which statements are executed; this order is called *flow of control.*

2.9 (Optional Case Study) Thinking About Objects: Examining the Problem Statement

Now we begin our optional, object-oriented design and implementation case study. The "Thinking About Objects" sections at the ends of this and the next several chapters will ease you into object orientation by examining an elevator simulation case study. This case study will provide you with a substantial, carefully paced, complete design and implementation experience. In Chapters 3 through 13, Chapter 15 and Chapter 22, we will perform the various steps of an object-oriented design (OOD) process using the UML while relating to the object-oriented concepts discussed in the chapters. In Appendices G, H and I, we will implement the elevator simulator using the techniques of object-oriented programming (OOP) in Java. We present the complete case-study solution. This is not an exercise; rather, it is an end-to-end learning experience that concludes with a detailed walkthrough of the actual Java code. We have provided this case study so that you can become accustomed to the kinds of substantial problems encountered in industry. We hope you enjoy this learning experience.

Problem Statement

A company intends to build a two-floor office building and equip it with an elevator. The company wants you to develop an object-oriented *software-simulator application* in Java that models the operation of the elevator to determine whether it will meet the company's needs. The company wants the simulation to contain an elevator system. The application consists of three parts. The first and most substantial part is the simulator, which *models* the operation of the elevator system. The second part is the display of this model on screen so that the user may *view* it graphically. The final part is the *graphical user interface*, or *GUI*, that allows the user to *control* the simulation. Our design and implementation will follow the so-called *Model-View-Controller architecture* we will learn about in Section 13.17.

The elevator system consists of an elevator shaft and an elevator car. In our simulation, we model people who ride the elevator car (referred to as "the elevator") to travel between the floors in the elevator shaft, as shown in Fig. 2.22, Fig. 2.23 and Fig. 2.24.

The elevator contains a door (called the "elevator door") that opens upon the elevator's arrival at a floor and closes upon the elevator's departure from that floor. The elevator door is closed during the trips between floors to prevent the passenger from being injured by brushing against the wall of the elevator shaft. In addition, the elevator shaft connects to a door on each floor (referred to as the two "floor doors"), so people cannot fall down the shaft when the elevator is not at a floor. Note that we do not display the floor doors in the figures, because they would obscure the inside of the elevator (we use a mesh door to rep-

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resent the elevator door because mesh allows us to see inside the elevator). The floor door opens concurrently with the elevator door, so it appears as if both doors open at the same time. A person sees only one door, depending on that person's location. When the person is inside the elevator, the person sees the elevator door and can exit the elevator when this door opens; when the person is outside the elevator, the person sees the floor door and can enter the elevator when that door opens[1].

The elevator starts on the first floor with all the doors closed. To conserve energy, the elevator moves only when necessary. For simplicity, the elevator and floors each have a capacity of only one person.[2]

The user of our application should, at any time, be able to create a unique person in the simulation and situate that person on either the first or second floor (Fig. 2.22). When created, the person walks across the floor to the elevator. The person then presses a button on the floor next to the elevator shaft (referred to as a "floor button"). When pressed, that floor button illuminates, then requests the elevator. When summoned, the elevator travels to the person's floor. If the elevator is already on that person' floor, the elevator does not travel. Upon arrival, the elevator resets the button inside the elevator (called the "elevator button"), sounds the bell inside the elevator, then opens the elevator door (which opens the floor door on that floor). The elevator then signals the elevator shaft of the arrival. The elevator shaft, upon receiving this message, resets the floor button and illuminates the light on that floor.

Occasionally, a person requests the elevator when it is moving. If the request was generated at the floor from which the elevator just departed, the elevator must "remember" to revisit that floor after carrying the current passenger to the other floor.

When the floor door opens, the person enters the elevator after the elevator passenger (if there is one) exits. If a person neither enters nor requests the elevator, the elevator closes its door and remains on that floor until the next person presses a floor button to summon the elevator.

When a person enters the elevator, that person presses the elevator button, which also illuminates when pressed. The elevator closes its door (which also closes the floor door on that floor) and moves to the opposite floor. The elevator takes five seconds to travel between floors. When the elevator arrives at the destination floor, the elevator door opens (along with the floor door on that floor) and the person exits the elevator.

The application user introduces a person onto the first or second floor by pressing the **First Floor** button or the **Second Floor** button, respectively. When the user presses the **First Floor** button, a person should be created (by the elevator simulation) and positioned on the first floor of the building. When the user presses the **Second Floor** button, a person should be created and positioned on the second floor. Over time, the user can create any number of people in the simulation, but the user cannot create a new person on an occupied floor. For example, Fig. 2.22 shows that the **First Floor** button is disabled to prevent the user from creating more than one person on the first floor. Figure 2.23 shows that this button is reenabled when the person rides the elevator.

---

1. Most people do not consider this when riding an elevator—they really think of one "elevator door," when in reality, there is a door in the elevator and a door on the floor, and these doors open and close in tandem.
2. After you have studied this case study, you may want to modify it to allow more than one person to ride the elevator at once and more than one person to wait on each floor at once.

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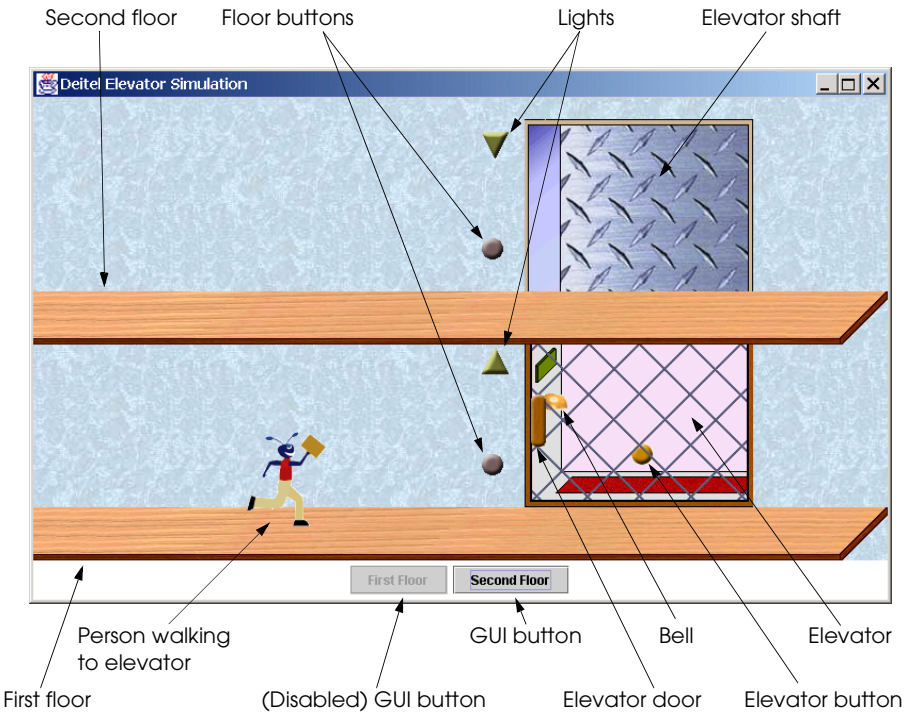

Fig. 2.22 Person moving towards elevator on the first floor.

Fig. 2.23 Person riding the elevator to the second floor.

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The company requests that we display the results of the simulation graphically, as shown in Fig. 2.22, Fig. 2.23 and Fig. 2.24. At various points in time, the screen should display a person walking to the elevator, pressing a button and entering, riding and exiting the elevator. The display also should also show the elevator moving, the doors opening, the lights turning on and off, the buttons illuminating when they are pressed and the buttons darkening when they are reset.

The company requests that audio be integrated into the simulation. For example, as a person walks, the application user should hear the footsteps. Each time a floor or elevator button is pressed or reset, the user should hear a click. The bell should ring upon the elevator's arrival, and doors should creak when they open or close. Lastly, "elevator music" should play as the elevator travels between floors.

Analyzing and Designing the Elevator System

We must analyze and design our system before we implement it as Java code. The output of the analysis phase is intended to specify clearly in a *requirements document* what the system is supposed to do. The requirements document for this case study is essentially the description of what the elevator simulator is supposed to do—presented informally in the last few pages. The output of the design phase should specify clearly *how* the system should be constructed to do what is needed. In the next several "Thinking About Objects" sections, we perform the steps of an object-oriented design (OOD) process on the elevator system. The UML is designed for use with any OOD process—many such processes exist. One popular method is the Rational Unified Process™ developed by Rational Software Corporation. For this case study, we present our own simplified design process. For many of our readers, this will be their first OOD/UML experience.

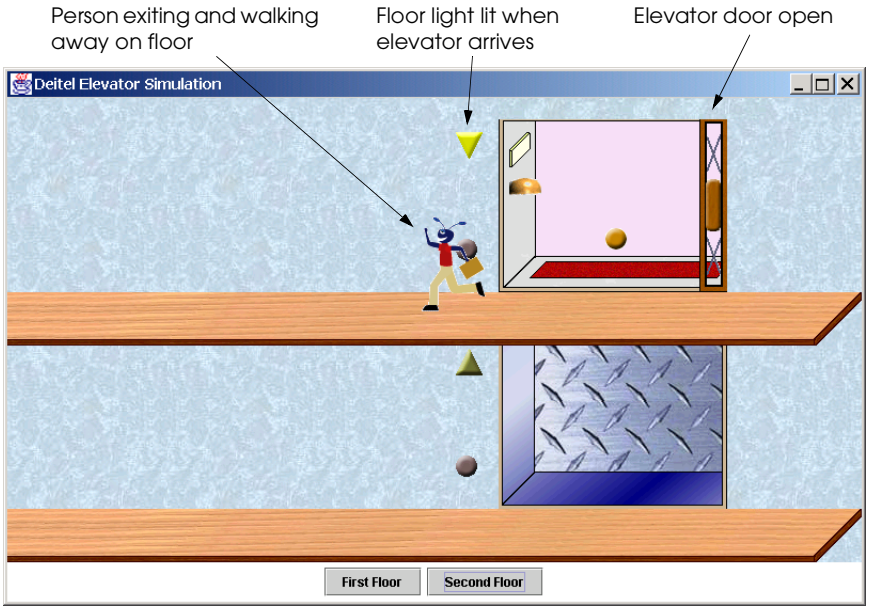

Fig. 2.24 Person walking away from elevator.

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We now begin the design phase of our elevator system, which will span Chapters 2 through 13, Chapter 15 and Chapter 22, in which we gradually develop the design. Appendices G, H and I present the complete Java implementation.

A system is a set of components that interact to solve a problem. In our case study, the elevator-simulator application represents the system. A system may contain "subsystems," which are "systems within a system." Subsystems simplify the design process by managing subsets of system responsibilities. System designers may allocate system responsibilities among the subsystems, design the subsystems, then integrate the subsystems with the overall system. Our elevator-simulation system contains three subsystems, which are defined in the problem statement:

1. the simulator model (which represents the operation of the elevator system),
2. the display of this model on screen (so that the user may view it graphically), and
3. the graphical user interface (that allows the user to control the simulation).

We develop the simulator model gradually through Chapter 15 and present the implemented model in Appendix H. We discuss the GUI components allowing the user to control the model in Chapter 12 and introduce how the subsystems work together to form the system in Chapter 13. Finally, we introduce how to display the simulator model on the screen in Chapter 22 and conclude the display in Appendix I.

System *structure* describes the system's objects and their inter-relationships. System *behavior* describes how the system changes as its objects interact with each other. Every system has both structure and behavior—we must design both. However, there are several distinct *types* of system structures and behaviors. For example, the interaction among the objects in the system differs from the interaction between the user and the system, yet both are interactions that constitute the system behavior.

The UML specifies nine types of diagrams for modeling systems. Each diagram models a distinct characteristic of a system's structure or behavior—the first four diagrams relate to system structure; the remaining five diagrams relate to system behavior:

1. Class diagram
2. Object diagram
3. Component diagram
4. Deployment diagram
5. Activity diagram
6. Statechart diagram
7. Collaboration diagram
8. Sequence diagram
9. Use-Case diagram

Class diagrams, which we explain in "Thinking About Objects" Section 3.8, model the classes, or "building blocks," used to build a system. Each entity in the problem statement is a candidate to be a class in the system (i.e., **`Person`**, **`Elevator`**, **`Floor`**, etc.).

Object diagrams, which we also explain in Section 3.8, model a "snapshot" of the system by modeling a system's objects and their relationships at a specific point in time. Each object represents an instance of a class from the class diagram (e.g., the elevator

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object is an instance of class **`Elevator`**), and there may be several objects created from one class (e.g., both the first floor button object and the second floor button object are created from class **`FloorButton`**).

Component diagrams, presented in Section 13.17, model the *components*—resources (which include graphics and audio) and *packages* (which are groups of classes)—that make up the system.

Deployment diagrams model the runtime requirements of the system (such as the computer or computers on which the system will reside), memory requirements for the system, or other devices the system requires during execution. We do not present deployment diagrams in this case study, because we are not designing a "hardware-specific" system—our simulation requires only one computer containing the Java 2 runtime environment on which to run.

Statechart diagrams, which we introduce in Section 5.11, model *how* an object changes *state* (i.e., the condition of an object at a specific time). When an object changes state, that object may behave differently in the system.

Activity diagrams, which we also introduce in Section 5.11, model an object's *activity*—that object's workflow during program execution. An activity diagram is a flowchart that models the actions the object will perform and in what order.

Both *collaboration diagrams* and *sequence diagrams* model the interactions among the objects in a system. Collaboration diagrams emphasize what interactions occur, whereas sequence diagrams emphasize when interactions occur. We introduce these diagrams in Section 7.10 and Section 15.12, respectively.

Use-Case diagrams represent the interaction between the user and our system (i.e., all actions the user may perform on the system). We introduce use-case diagrams in Section 12.16, where we discuss user-interface issues.

In "Thinking About Objects" Section 3.17, we continue designing our elevator system by identifying the classes in the problem statement. We accomplish this by extracting all the nouns and noun clauses from the problem statement. Using these classes, we develop a class diagram that models the structure of our elevator simulation system.

Internet and World-Wide-Web Resources

Listed below are URLs and books on object-oriented design with the UML—you may find these references helpful as you study the remaining sections of our case-study presentation.

`www.omg.com/technology/uml/index.htm`
This is the UML resourse page from the Object Management Group, which provides specifications for various object-oriented technologies, such as the UML.

`www.smartdraw.com/drawing/software/indexUML.asp`
This site shows how to draw UML diagrams without the use of modeling tools.

`www.rational.com/uml/index.jsp`
This is the UML resource page for Rational Software Corporation—the company that created the UML.

`microgold.com/Stage/UML_FAQ.html`
This site provides the UML FAQ maintained by Rational Software.

`www.softdocwiz.com/Dictionary.htm`
This site hosts the Unified Modeling Language Dictionary, which lists and defines all terms used in the UML.

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www.embarcadero.com
This site provides a free 30-day license to download a trial-version of Describe™— the new UML modeling tool from Embarcadero Technologies®.

www.ics.uci.edu/pub/arch/uml/uml_books_and_tools.html
This site lists books on the UML and software tools that use the UML, such as Rational Rose™ and Embarcadero Describe™.

www.ootips.org/ood-principles.html
This site provides answers to the question "what makes good OOD?"

wdvl.internet.com/Authoring/Scripting/Tutorial/oo_design.html
This site introduces OOD and provides OOD resources.

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SUMMARY

- An application is a program that executes using the **`java`** interpreter.
- A comment that begins with **`//`** is called a single-line comment. Programmers insert comments to document programs and improve program readability.
- A string of characters contained between double quotation marks is called a string, a character string, a message or a string literal.
- Blank lines, space characters, newline characters and tab characters are known as white-space characters. White-space characters outside strings are ignored by the compiler.

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- Keyword **`class`** introduces a class definition and is immediately followed by the class name.
- Keywords (or reserved words) are reserved for use by Java. Keywords must appear in all lowercase letters.
- By convention, all class names in Java begin with a capital letter. If a class name contains more than one word, the first letter of each word should be capitalized.
- An identifier is a series of characters consisting of letters, digits, underscores (_) and dollar signs (**`$`**) that does not begin with a digit, does not contain any spaces and is not a keyword.
- Java is case sensitive—that is, uppercase and lowercase letters are different.
- A left brace, **`{`**, begins the body of every class definition. A corresponding right brace, **`}`**, ends each class definition.
- Java applications begin executing at method **`main`**.
- Methods are able to perform tasks and return information when they complete their tasks.
- The first line of method **`main`** must be defined as

```
public static void main( String args[] )
```

- A left brace, **`{`**, begins the body of a method definition. A corresponding right brace, **`}`**, ends the method definition's body.
- **`System.out`** is known as the standard output object. **`System.out`** allows Java applications to display strings and other types of information in the command window from which the Java application executes.
- The escape sequence **`\n`** indicates a newline character. Other escape sequences include **`\t`** (tab), **`\r`** (carriage return), **`\\`** (backslash) and **`\"`** (double quote).
- Method **`println`** of the **`System.out`** object displays (or prints) a line of information in the command window. When **`println`** completes its task, it automatically positions the output cursor to the beginning of the next line in the command window.
- Every statement must end with a semicolon (also known as the statement terminator).
- The difference between **`System.out`**'s **`print`** and **`println`** methods is that **`print`** does not position to the beginning of the next line in the command window when it finishes displaying its argument. The next character displayed in the command window appears immediately after the last character displayed with **`print`**.
- Java contains many predefined classes that are grouped into categories of related classes called packages. The packages are referred to collectively as the Java class library or the Java applications programming interface (Java API).
- Class **`JOptionPane`** is defined in package **`javax.swing`**. Class **`JOptionPane`** contains methods that display dialog boxes.
- The compiler uses **`import`** statements to locate classes required to compile a Java program.
- The **`javax.swing`** package contains many classes that help define a graphical user interface (GUI) for an application. GUI components facilitate data entry by the user of a program and data outputs by a program.
- Method **`showMessageDialog`** of class **`JOptionPane`** displays a dialog box containing a message to the user.
- A **`static`** method is called by following its class name by a dot (**`.`**) and the name of the method.
- Method **`exit`** of class **`System`** terminates an application. Class **`System`** is in package **`java.lang`**. All Java programs import package **`java.lang`** by default.

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- A variable is a location in the computer's memory where a value can be stored for use by a program. The name of a variable is any valid identifier.
- All variables must be declared with a name and a data type before they can be used in a program.
- Declarations end with a semicolon (`;`) and can be split over several lines, with each variable in the declaration separated by a comma (forming a comma-separated list of variable names).
- Variables of type `int` hold integer values (whole numbers such as 7, –11, 0 and 31,914).
- Types such as `int`, `float`, `double` and `char` are primitive data types. Names of primitive data types are keywords of the Java programming language.
- A prompt directs the user to take a specific action.
- A variable is assigned a value by using an assignment statement, which uses the assignment operator, `=`. The `=` operator is called a binary operator, because it has two operands.
- Method `Integer.parseInt` (a `static` method of class `Integer`) converts its `String` argument to an `int` value.
- Java has a version of the `+` operator for string concatenation that enables a string and a value of another data type (including another string) to be concatenated.
- Every variable has a name, a type, a size and a value.
- When a value is placed in a memory location, the value replaces the value previously in that location. When a value is read out of a memory location, the variable's value remains unchanged.
- The arithmetic operators are binary operators, because they operate on two operands.
- Integer division yields an integer result.
- Arithmetic expressions in Java must be written in straight-line form to facilitate entering programs into the computer.
- Operators in arithmetic expressions are applied in a precise sequence determined by the rules of operator precedence.
- Parentheses may be used to force the order of evaluation of operators.
- When we say that operators are applied from left to right, we are referring to the associativity of the operators. Some operators associate from right to left.
- Java's `if` structure allows a program to make a decision based on the truth or falsity of a condition. If the condition is met (i.e., the condition is true), the statement in the body of the `if` structure executes. If the condition is not met (i.e., the condition is false), the body statement does not execute.
- Conditions in `if` structures can be formed by using the equality operators and relational operators.
- The empty string is a string containing no characters.
- Every variable declared in a method must be initialized before it can be used in an expression.

TERMINOLOGY

addition operator (`+`)
applet
application
argument to a method
arithmetic operators
assignment operator (`=`)
assignment statement
associativity of operators
backslash (`\`) escape character
binary operator
body of a class definition
body of a method definition
braces (`{` and `}`)
case sensitive
character string
class
class definition
`.class` file extension
`class` keyword
class name

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command tool
command window
comma-separated list
comment (`//`)
compilation error
compile error
compiler
compile-time error
condition
decision
declaration
dialog
dialog box
division operator (`/`)
document a program
empty string (`""`)
equality operators
    `==` "is equal to"
    `!=` "is not equal to"
escape sequence
`exit` method of `System`
false
graphical user interface (GUI)
identifier
`if` structure
`import` statement
input dialog
`int` primitive type
integer (`int`)
`Integer` class
integer division
interpreter
Java
Java 2 Software Development Kit (J2SDK)
Java applications programming interface (API)
Java class library
Java documentation comment
`.java` file extension
`java` interpreter
`java.lang` package
`javax.swing` package
`JOptionPane` class
`JOptionPane.ERROR_MESSAGE`
`JOptionPane.INFORMATION_MESSAGE`
`JOptionPane.PLAIN_MESSAGE`
`JOptionPane.QUESTION_MESSAGE`
`JOptionPane.WARNING_MESSAGE`
left brace, `{`, begins the body of a class
left brace, `{`, begins the body of a method
literal
`main` method
memory
memory location
message
message dialog
method
Microsoft Internet Explorer browser
modulus operator (`%`)
mouse cursor
mouse pointer
MS-DOS Prompt
multiple-line comment
multiplication operator (`*`)
nested parentheses
Netscape Navigator browser
newline character (`\n`)
object
operand
operator
package
parentheses `()`
`parseInt` method of class `Integer`
precedence
primitive data type
programmer-defined class
prompt
`public` keyword
relational operators
    `<` "is less than"
    `<=` "is less than or equal to"
    `>` "is greater than
    `>=` "is greater than or equal to"
reserved words
right brace, `}`, ends the body of a class
right brace, `}`, ends the body of a method
right-to-left associativity
rules of operator precedence
semicolon (`;`) statement terminator
shell tool
`showInputDialog` method of `JOptionPane`
`showMessageDialog` method of
    `JOptionPane`
single-line comment
standard output object
statement
statement terminator (`;`)
`static` method
straight-line form
string
`String` class

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string concatenation
string concatenation operator (**+**)
subtraction operator (**-**)
syntax error
System class
System.out object
System.out.print method
System.out.println method
title bar of a dialog
true
user-defined class
variable
variable name
variable value
void keyword
white-space characters

SELF-REVIEW EXERCISES

2.1 Fill in the blanks in each of the following statements:

a) The _____ begins the body of every method, and the _____ ends the body of every method.
b) Every statement ends with a _____.
c) The _____ structure is used to make decisions.
d) _____ begins a single-line comment.
e) _____, _____, _____ and _____ are called white-space characters.
f) Class _____ contains methods that display message dialogs and input dialogs.
g) _____ are reserved for use by Java.
h) Java applications begin execution at method _____.
i) Methods _____ and _____ display information in the command window.
j) A _____ method is always called using its class name followed by a dot (**.**) and its method name.

2.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) Comments cause the computer to print the text after the **//** on the screen when the program is executed.
b) All variables must be given a type when they are declared.
c) Java considers the variables **number** and **NuMbEr** to be identical.
d) The modulus operator (**%**) can be used only with integer operands.
e) The arithmetic operators *****, **/**, **%**, **+** and **-** all have the same level of precedence.
f) Method **Integer.parseInt** converts an integer to a **String**.

2.3 Write Java statements to accomplish each of the following tasks:

a) Declare variables **c**, **thisIsAVariable**, **q76354** and **number** to be of type **int**.
b) Display a dialog asking the user to enter an integer.
c) Convert a **String** to an integer, and store the converted value in integer variable **age**. Assume that the **String** is stored in **value**.
d) If the variable **number** is not equal to **7**, display **"The variable number is not equal to 7"** in a message dialog. [*Hint*: Use the version of the message dialog that requires two arguments.]
e) Print the message **"This is a Java program"** on one line in the command window.
f) Print the message **"This is a Java program"** on two lines in the command window; the first line should end with **Java**. Use only one statement.

2.4 Identify and correct the errors in each of the following statements:

a)
```
if ( c < 7 );
   JOptionPane.showMessageDialog( null,
      "c is less than 7" );
```

b)
```
if ( c => 7 )
   JOptionPane.showMessageDialog( null,
      "c is equal to or greater than 7" );
```

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2.5 Write a statement (or comment) to accomplish each of the following tasks:

a) State that a program will calculate the product of three integers.
b) Declare the variables **x**, **y**, **z** and **result** to be of type **int**.
c) Declare the variables **xVal**, **yVal** and **zVal** to be of type **String**.
d) Prompt the user to enter the first value, read the value from the user and store it in the variable **xVal**.
e) Prompt the user to enter the second value, read the value from the user and store it in the variable **yVal**.
f) Prompt the user to enter the third value, read the value from the user and store it in the variable **zVal**.
g) Convert **xVal** to an **int**, and store the result in the variable **x**.
h) Convert **yVal** to an **int**, and store the result in the variable **y**.
i) Convert **zVal** to an **int**, and store the result in the variable **z**.
j) Compute the product of the three integers contained in variables **x**, **y** and **z**, and assign the result to the variable **result**.
k) Display a dialog containing the message **"The product is "** followed by the value of the variable **result**.
l) Return a value from the program indicating that the program terminated successfully.

2.6 Using the statements you wrote in Exercise 2.5, write a complete program that calculates and prints the product of three integers.

ANSWERS TO SELF-REVIEW EXERCISES

2.1 a) left brace (**{**), right brace (**}**). b) semicolon (**;**). c) **if**. d) **//**. e) Blank lines, space characters, newline characters and tab characters. f) **JOptionPane**. g) Keywords. h) **main**. i) **System.out.print** and **System.out.println**. j) **static**.

2.2 a) False. Comments do not cause any action to be performed when the program is executed. They are used to document programs and improve their readability.
b) True.
c) False. Java is case sensitive, so these variables are distinct.
d) False. The modulus operator can also be used with noninteger operands in Java.
e) False. The operators *****, **/** and **%** are on the same level of precedence, and the operators **+** and **-** are on a lower level of precedence.
f) False. **Integer.parseInt** method converts a **String** to an integer (**int**) value.

2.3 a)
```
int c, thisIsAVariable, q76354, number;
```
b)
```
value = JOptionPane.showInputDialog( "Enter an integer" );
```
c)
```
age = Integer.parseInt( value );
```
d)
```
if ( number != 7 )
   JOptionPane.showMessageDialog( null,
      "The variable number is not equal to 7" );
```
e)
```
System.out.println( "This is a Java program" );
```
f)
```
System.out.println( "This is a Java\nprogram" );
```

2.4 The solutions to Self-Review Exercise 2.4 are as follows:

a) Error: Semicolon after the right parenthesis of the condition in the **if** statement.
Correction: Remove the semicolon after the right parenthesis. [*Note*: The result of this error is that the output statement will be executedregardless of whether the condition in the **if** statement is true. The semicolon after the right parenthesis is considered an empty statement—a statement that does nothing. We will learn more about the empty statement in the next chapter.]

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b) Error: The relational operator **=>** is incorrect.
Correction: Change **=>** to **>=**.

2.5

```
a) // Calculate the product of three integers
b) int x, y, z, result;
c) String xVal, yVal, zVal;
d) xVal = JOptionPane.showInputDialog(
      "Enter first integer:" );
e) yVal = JOptionPane.showInputDialog(
      "Enter second integer:" );
f) zVal = JOptionPane.showInputDialog(
      "Enter third integer:" );
g) x = Integer.parseInt( xVal );
h) y = Integer.parseInt( yVal );
i) z = Integer.parseInt( zVal );
j) result = x * y * z;
k) JOptionPane.showMessageDialog( null,
      "The product is " + result );
l) System.exit( 0 );
```

2.6 The solution to Exercise 2.6 is as follows:

```
1  // Calculate the product of three integers
2
3  // Java extension packages
4  import javax.swing.JOptionPane;
5
6  public class Product {
7
8     public static void main( String args[] )
9     {
10       int x, y, z, result;
11       String xVal, yVal, zVal;
12
13       xVal = JOptionPane.showInputDialog(
14          "Enter first integer:" );
15       yVal = JOptionPane.showInputDialog(
16          "Enter second integer:" );
17       zVal = JOptionPane.showInputDialog(
18          "Enter third integer:" );
19
20       x = Integer.parseInt( xVal );
21       y = Integer.parseInt( yVal );
22       z = Integer.parseInt( zVal );
23
24       result = x * y * z;
25       JOptionPane.showMessageDialog( null,
26          "The product is " + result );
27
28       System.exit( 0 );
29    }
30 }
```

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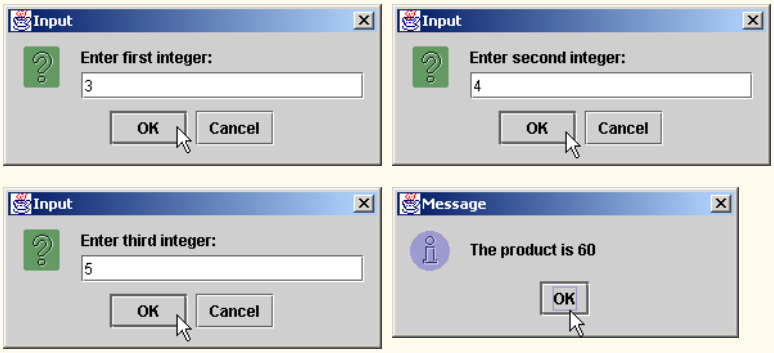

EXERCISES

2.7 Fill in the blanks in each of the following statements:

a) _____ are used to document a program and improve its readability.

b) An input dialog capable of receiving input from the user is displayed with method _____ of class _____.

c) A decision can be made in a Java program with an _____.

d) Calculations are normally performed by _____ statements.

e) A dialog capable of displaying a message to the user is displayed with method _____ of class _____.

2.8 Write Java statements that accomplish each of the following tasks:

a) Display the message **"Enter two numbers"**, using class **JOptionPane**.

b) Assign the product of variables **b** and **c** to variable **a**.

c) State that a program performs a sample payroll calculation (i.e., use text that helps to document a program).

2.9 State whether each of the following is *true* or *false*. If *false*, explain why.

a) Java operators are evaluated from left to right.

b) The following are all valid variable names: **_under_bar_**, **m928134**, **t5**, **j7**, **her_sales$**, **his_$account_total**, **a**, **b$**, **c**, **z**, **z2**.

c) A valid Java arithmetic expression with no parentheses is evaluated from left to right.

d) The following are all invalid variable names: **3g**, **87**, **67h2**, **h22**, **2h**.

2.10 Fill in the blanks in each of the following statements:

a) What arithmetic operations have the same precedence as multiplication? _____.

b) When parentheses are nested, which set of parentheses is evaluated first in an arithmetic expression? _____.

c) A location in the computer's memory that may contain different values at various times throughout the execution of a program is called a _____.

2.11 What displays in the message dialog when each of the given Java statements is performed? Assume that **x = 2** and **y = 3**.

a)
```
JOptionPane.showMessageDialog( null, "x = " + x );
```

b)
```
JOptionPane.showMessageDialog( null,
   "The value of x + x is " + ( x + x ) );
```

c)
```
JOptionPane.showMessageDialog( null, "x =" );
```

d)
```
JOptionPane.showMessageDialog( null,
   ( x + y ) + " = " + ( y + x ) );
```

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2.12 Which of the following Java statements contain variables whose values are changed or replaced?

a) `p = i + j + k + 7;`

b)
```
JOptionPane.showMessageDialog( null,
   "variables whose values are destroyed" );
```

c) `JOptionPane.showMessageDialog( null, "a = 5" );`

d) `stringVal = JOptionPane.showInputDialog( "Enter string: );`

2.13 Given that $y = ax^3 + 7$, which of the following are correct Java statements for this equation?

a) `y = a * x * x * x + 7;`

b) `y = a * x * x * ( x + 7 );`

c) `y = ( a * x ) * x * ( x + 7 );`

d) `y = ( a * x ) * x * x + 7;`

e) `y = a * ( x * x * x ) + 7;`

f) `y = a * x * ( x * x + 7 );`

2.14 State the order of evaluation of the operators in each of the following Java statements, and show the value of `x` after each statement is performed:

a) `x = 7 + 3 * 6 / 2 - 1;`

b) `x = 2 % 2 + 2 * 2 - 2 / 2;`

c) `x = ( 3 * 9 * ( 3 + ( 9 * 3 / ( 3 ) ) ) );`

2.15 Write an application that displays the numbers 1 to 4 on the same line, with each pair of adjacent numbers separated by one space. Write the program using the following methods:

a) Using one `System.out` statement.

b) Using four `System.out` statements.

2.16 Write an application that asks the user to enter two numbers, obtains the numbers from the user and prints the sum, product, difference and quotient (division) of the numbers. Use the techniques shown in Fig. 2.9.

2.17 Write an application that asks the user to enter two integers, obtains the numbers from the user and displays the larger number followed by the words "`is larger`" in an information message dialog. If the numbers are equal, print the message "`These numbers are equal`." Use the techniques shown in Fig. 2.20.

2.18 Write an application that inputs three integers from the user and displays the sum, average, product, smallest and largest of the numbers in an information message dialog. Use the GUI techniques shown in Fig. 2.20. [*Note*: The calculation of the average in this exercise should result in an integer representation of the average. So, if the sum of the values is 7, the average should be 2, not 2.3333….]

2.19 Write an application that inputs from the user the radius of a circle and prints the circle's diameter, circumference and area. Use the value 3.14159 for π. Use the GUI techniques shown in Fig. 2.9. [*Note*: You may also use the predefined constant `Math.PI` for the value of π. This constant is more precise than the value 3.14159. Class `Math` is defined in the `java.lang` package, so you do not need to `import` it.] Use the following formulas (r is the radius):

$diameter = 2r$
$circumference = 2\pi r$
$area = \pi r^2$

2.20 Write an application that displays in the command window a box, an oval, an arrow and a diamond using asterisks (`*`), as follows:

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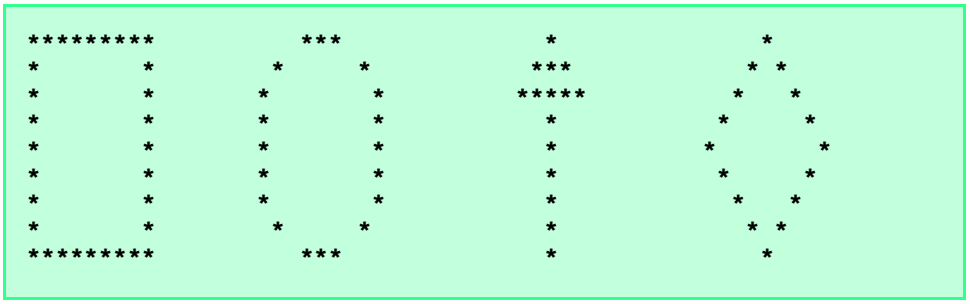

2.21 Modify the program you created in Exercise 2.20 to display the shapes in a **`JOptionPane.PLAIN_MESSAGE`** dialog. Does the program display the shapes exactly as in Exercise 2.20?

2.22 What does the following code print?

```
System.out.println( "*\n**\n***\n****\n*****" );
```

2.23 What does the following code print?

```
System.out.println( "*" );
System.out.println( "****" );
System.out.println( "******" );
System.out.println( "*****" );
System.out.println( "***" );
```

2.24 What does the following code print?

```
System.out.print( "*" );
System.out.print( "****" );
System.out.print( "******" );
System.out.print( "*****" );
System.out.println( "***" );
```

2.25 What does the following code print?

```
System.out.print( "*" );
System.out.println( "****" );
System.out.println( "******" );
System.out.print( "*****" );
System.out.println( "***" );
```

2.26 Write an application that reads five integers and determines and prints the largest and the smallest integers in the group. Use only the programming techniques you learned in this chapter.

2.27 Write an application that reads an integer and determines and prints whether it is odd or even. [*Hint*: Use the modulus operator. An even number is a multiple of 2. Any multiple of 2 leaves a remainder of 0 when divided by 2.]

2.28 Write an application that reads in two integers and determines and prints if the first is a multiple of the second. [*Hint*: Use the modulus operator.]

2.29 Write an application that displays in the command window a checkerboard pattern as follows:

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```
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
```

2.30 Modify the program you wrote in Exercise 2.29 to display the checkerboard pattern in a **`JOptionPane.PLAIN_MESSAGE`** dialog. Does the program display the shapes exactly as in Exercise 2.29?

2.31 Here's a peek ahead. In this chapter, you have learned about integers and the data type **`int`**. Java can also represent uppercase letters, lowercase letters and a considerable variety of special symbols. Every character has a corresponding integer representation. The set of characters a computer uses and the corresponding integer representations for those characters is called that computer's *character set*. You can indicate a character value in a program simply by enclosing that character in single quotes, as in **`'A'`**.

You can determine the integer equivalent of a character by preceding that character with **`(int)`**. This form is called a cast (we will say more about casts in Chapter 4) as in:

```
(int) 'A'
```

The following statement outputs a character and its integer equivalent:

```
System.out.println( "The character " + 'A' +
   " has the value " + ( int ) 'A' );
```

When the preceding statement executes, it displays the character **`A`** and the value **`65`** (from the so-called Unicode character set) as part of the string.

Write an application that displays the integer equivalents of some uppercase letters, lowercase letters, digits and special symbols. At a minimum, display the integer equivalents of the following: **`A B C a b c 0 1 2 $ * + /`** and the blank character.

2.32 Write an application that inputs one number consisting of five digits from the user, separates the number into its individual digits and prints the digits separated from one another by three spaces each. For example, if the user types in the number **`42339`**, the program should print

```
4   2   3   3   9
```

[*Hint*: It is possible to do this exercise with the techniques you learned in this chapter. You will need to use both division and modulus operations to "pick off" each digit.]

Assume that the user enters the correct number of digits. What happens when you execute the program and type a number with more than five digits? What happens when you execute the program and type a number with fewer than five digits?

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2.33 Using only the programming techniques you learned in this chapter, write an application that calculates the squares and cubes of the numbers from 0 to 10 and prints the resulting values in table format as follows:

```
number  square  cube
0       0       0
1       1       1
2       4       8
3       9       27
4       16      64
5       25      125
6       36      216
7       49      343
8       64      512
9       81      729
10      100     1000
```

[*Note*: This program does not require any input from the user.]

2.34 Write a program that reads a first name and a last name from the user as two separate inputs and concatenates the first name and last name, separating them by a space. Display in a message dialog the concatenated name.

2.35 Write a program that inputs five numbers and determines and prints the number of negative numbers input, the number of positive numbers input and the number of zeros input.

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3

Introduction to Java Applets

Objectives

- To observe some of Java's exciting capabilities through the Java 2 Software Development Kit's demonstration applets.
- To differentiate between applets and applications.
- To be able to write simple Java applets.
- To be able to write simple Hypertext Markup Language (HTML) files to load an applet into the **`appletviewer`** or a World Wide Web browser.
- To understand the difference between variables and references.
- To execute applets in World Wide Web browsers.

He would answer to "Hi!" or to any loud cry
Such as "Fry me!" or "Fritter my wig!"
To "What-you-may-call-um!" or "What-was-his-name!"
But especially "Thing-um-a-jig!"
Lewis Carroll

Painting is only a bridge linking the painter's mind with that of the viewer.
Eugène Delacroix

My method is to take the utmost trouble to find the right thing to say, and then to say it with the utmost levity.
George Bernard Shaw

Though this be madness, yet there is method in 't.
William Shakespeare

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Outline

3.1 Introduction
3.2 Sample Applets from the Java 2 Software Development Kit
3.2.1 The TicTacToe Applet
3.2.2 The DrawTest Applet
3.2.3 The Java2D Applet
3.3 A Simple Java Applet: Drawing a String
3.3.1 Compiling and Executing `WelcomeApplet`
3.4 Two More Simple Applets: Drawing Strings and Lines
3.5 Another Java Applet: Adding Floating-Point Numbers
3.6 Viewing Applets in a Web Browser
3.6.1 Viewing Applets in Netscape Navigator 6
3.6.2 Viewing Applets in Other Browsers Using the Java Plug-In
3.7 Java Applet Internet and World Wide Web Resources
3.8 (Optional Case Study) Thinking About Objects: Identifying the Classes in a Problem Statement

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

3.1 Introduction

In Chapter 2, we introduced Java application programming and several important aspects of Java applications. This chapter introduces another type of Java program called a Java applet. Applets are Java programs that can be embedded in *Hypertext Markup Language (HTML) documents (i.e.,* Web pages). When a browser loads a Web page containing an applet, the applet downloads into the Web browser and begins execution.

The browser that executes an applet is generically known as the *applet container*. The Java 2 Software Development Kit (J2SDK) includes an applet container (called the **`appletviewer`**) for testing applets before you embed them in a Web page. Most Web browsers in use today do not support Java 2 directly. For this reason, we normally demonstrate our applets using the **`appletviewer`**. One browser that does support Java 2 is Netscape Navigator 6. To execute applets in other Web browsers such as Microsoft Internet Explorer or earlier versions of Netscape Navigator requires the *Java Plug-in*, which we discuss in Section 3.6.2 of this chapter.

Portability Tip 3.1

Most Web browsers in use today do not support applets written in Java 2. To execute applets in such browsers, you must use the Java Plug-in (see Section 3.6.2).

Testing and Debugging Tip 3.1

*Test your applets in the **`appletviewer`** applet container before executing them in a Web browser. This enables you to see error messages that may occur. Also, once an applet is executing in a browser, it is sometimes difficult to reload the applet after making changes to the applet's class definition.*

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Testing and Debugging Tip 3.2

Test your applets in every Web browser in which the applets will execute to ensure that they operate correctly in each browser.

One of our goals in this chapter is to mimic several features presented in Chapter 2. This provides positive reinforcement of previous concepts. Another goal of this chapter is to begin using the object-oriented programming terminology introduced in Section 1.15.

As in Chapter 2, there are a few cases where we do not as yet provide all the details necessary to create complex applications and applets in Java. It is important to build your knowledge of fundamental programming concepts first. In Chapter 4 and Chapter 5, we present a detailed treatment of *program development* and *program control* in Java. As we proceed through the text, we present many substantial applications and applets.

3.2 Sample Applets from the Java 2 Software Development Kit

We begin by considering several sample applets provided with the Java 2 Software Development Kit (J2SDK) version 1.3. The applets we demonstrate give you a sense of Java's capabilities. Each of the sample programs provided with the J2SDK also comes with *source code* (the **.java** files containing the Java applet programs). This source code is helpful as you enhance your Java knowledge—you can read the source code provided to learn new and exciting features of Java. Remember, all programmers initially learn new features by mimicking their use in existing programs. The J2SDK comes with many such programs and there are a tremendous number of Java resources on the Internet and World Wide Web that include Java source code.

The demonstration programs provided with the J2SDK are located in your J2SDK install directory in a subdirectory called **demo**. For the Java 2 Software Development Kit version 1.3, the default location of the **demo** directory on Windows is

```
c:\jdk1.3\demo
```

On UNIX/Linux it is the directory in which you install the J2SDK followed by **jdk1.3/demo**—for example

```
/usr/local/jdk1.3/demo
```

For other platforms, there will be a similar directory (or folder) structure. For the purpose of this chapter, we assume on Windows that the J2SDK is installed in **c:\jdk1.3** and on UNIX that the J2SDK is installed in your home directory in **~/jdk1.3**. [*Note:* You may need to update these locations to reflect your chosen install directory and/or disk drive, or a newer version of the J2SDK.]

If you are using a Java Development tool that does not come with the Sun Java demos, you can download the J2SDK (with the demos) from the Sun Microsystems Java Web site

```
java.sun.com/j2se/1.3/
```

3.2.1 The TicTacToe Applet

The first applet we demonstrate from the J2SDK demos is the **TicTacToe** applet, which allows you to play Tic-Tac-Toe against the computer. To execute this applet, open a com-

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mand window (*MS-DOS Prompt* on Windows 95/98/ME, *Command Prompt* on Windows NT/2000 or a *command tool/shell tool* on UNIX) and change directories to the J2SDK's **demo** directory. Both Windows and UNIX use command ***cd*** to ***c****hange* ***d****irectories*. For example, the command

```
cd c:\jdk1.3\demo
```

changes to the **demo** directory on Windows and the command

```
cd ~/jdk1.3/demo
```

changes to the **demo** directory on UNIX.

The **demo** directory contains four subdirectories—***applets***, ***jfc***, ***jpda*** and ***sound*** (you can see these directories by issuing in the command window the **dir** command on Windows or the **ls** command on UNIX). The **applets** directory contains many demonstration applets. The **jfc** (Java Foundation Classes) directory contains many examples of Java's newest graphics and GUI features (some of these examples are also applets). The **jdpa** directory contains examples of the *Java Platform Debugging Architecture* (beyond the scope of this book). The sound directory contains examples of the *Java Sound API* (covered in Chapter 18). For the demonstrations in this section, change directories to the **applets** directory by issuing the command

```
cd applets
```

on either Windows or UNIX.

Listing the contents of the **applets** directory (with the **dir** command on Windows or the **ls** command on UNIX) indicates that there are many examples. Figure 3.1 shows the subdirectories and provides a brief description of the examples in each subdirectory.

Example	Description
Animator	Performs one of four separate animations.
ArcTest	Demonstrates drawing arcs. You can interact with the applet to change attributes of the arc that is displayed.
BarChart	Draws a simple bar chart.
Blink	Displays blinking text in different colors.
CardTest	Demonstrates several GUI components and a variety of ways in which GUI components can be arranged on the screen (the arrangement of GUI components is also known as the *layout* of the GUI components).
Clock	Draws a clock with rotating "hands," the current date and the current time. The clock is updated once per second.
DitherTest	Demonstrates drawing with a graphics technique known as dithering that allows gradual transformation from one color to another.

Fig. 3.1 The examples from the **applets** directory (part 1 of 2).

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Example	Description
DrawTest	Allows the user to drag the mouse to draw lines and points on the applet in different colors.
Fractal	Draws a fractal. Fractals typically require complex calculations to determine how they are displayed.
GraphicsTest	Draws a variety of shapes to illustrate graphics capabilities.
GraphLayout	Draws a graph consisting of many nodes (represented as rectangles) connected by lines. Drag a node to see the other nodes in the graph adjust on the screen and demonstrate complex graphical interactions.
ImageMap	Demonstrates an image with *hot spots*. Positioning the mouse pointer over certain areas of the image highlights the area and a message is displayed in the lower-left corner of the **appletviewer** window. Position over the mouth in the image to hear the applet say "hi."
JumpingBox	Moves a rectangle randomly around the screen. Try to catch it by clicking it with the mouse!
MoleculeViewer	Presents a three-dimensional view of several different chemical molecules. Drag the mouse to view the molecule from different angles.
NervousText	Draws text that jumps around the screen.
SimpleGraph	Draws a complex curve.
SortDemo	Compares three sorting techniques. Sorting (described in Chapter 7) arranges information in order—like alphabetizing words. When you execute the applet, three **appletviewer** windows appear. Click in each one to start the sort. Notice that the sorts all operate at different speeds.
SpreadSheet	Demonstrates a simple spreadsheet of rows and columns.
SymbolTest	Draws characters from the Java character set.
TicTacToe	Allows the user to play Tic-Tac-Toe against the computer.
WireFrame	Draws a three-dimensional shape as a wire frame. Drag the mouse to view the shape from different angles.

Fig. 3.1 The examples from the **applets** directory (part 2 of 2).

Change directories to subdirectory **TicTacToe**. In that directory you will find the HTML file **example1.html** that is used to execute the applet. In the command window, type the command

```
appletviewer example1.html
```

and press the *Enter* key. This executes the **appletviewer**. The **appletviewer** loads the HTML file specified as its *command-line argument* (**example1.html**), determines from the file which applet to load (we discuss the details of HTML files in Section 3.3) and begins executing the applet. Figure 3.2 shows several screen captures of playing Tic-Tac-Toe with this applet.

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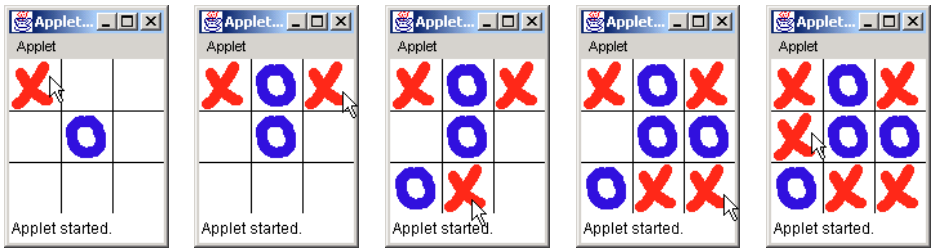

Fig. 3.2 Sample execution of the `TicTacToe` applet.

Testing and Debugging Tip 3.3

If the **`appletviewer`** *command does not work and/or the system indicates that the* **`appletviewer`** *command cannot be found, the* **`PATH`** *environment variable may not be defined properly on your computer. Review the installation directions for the Java 2 Software Development Kit to ensure that the* **`PATH`** *environment variable is defined correctly for your system (on some computers, you may need to restart your computer after modifying the* **`PATH`** *environment variable).*

You are player **X**. To interact with the applet, point the mouse at the square where you want to place an **X** and click the mouse button (normally, the left mouse button). The applet plays a sound (assuming your computer supports audio playback) and places an **X** in the square if the square is open. If the square is occupied, this is an invalid move and the applet plays a different sound indicating that you cannot make the specified move. After you make a valid move, the applet responds by making its own move (this happens quickly).

To play again, re-execute the applet by clicking the **`appletviewer`**'s ***Applet*** *menu* and selecting the ***Reload*** *menu item* (Fig. 3.3). To terminate the **`appletviewer`**, click the **`appletviewer`**'s **Applet** menu and select the ***Quit*** *menu item*.

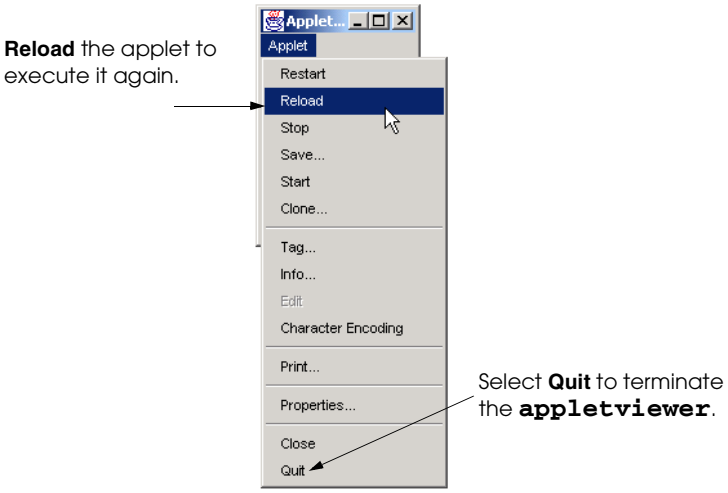

Fig. 3.3 Selecting **Reload** from the **`appletviewer`**'s **Applet** menu.

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3.2.2 The DrawTest Applet

The next applet we demonstrate allows you to draw lines and points in different colors. To draw, you simply drag the mouse on the applet by pressing a mouse button and holding it while you drag the mouse. For this example, change directories to directory **`applets`**, then to subdirectory **`DrawTest`**. In that directory is the **`example1.html`** file that is used to execute the applet. In the command window, type the command

```
appletviewer example1.html
```

and press the *Enter* key. This executes the **`appletviewer`**. The **`appletviewer`** loads the HTML file specified as its command-line argument (**`example1.html`** again), determines from the file which applet to load and begins execution of the applet. Figure 3.4 shows a screen capture of this applet after drawing some lines and points.

The default shape to draw is a line and the default color is black, so you can draw black lines by dragging the mouse across the applet. To drag the mouse, press and hold the mouse button and move the mouse. Notice that the line follows the mouse pointer around the applet. The line is not permanent until you release the mouse button. You can then start a new line by repeating the process.

Select a color by clicking the circle inside one of the colored rectangles at the bottom of the applet. You can select from red, green, blue, pink, orange and black. The GUI components used to present these options are commonly known as *radio buttons*. If you think of a car radio, only one radio station can be selected at a time. Similarly, only one drawing color can be selected at a time.

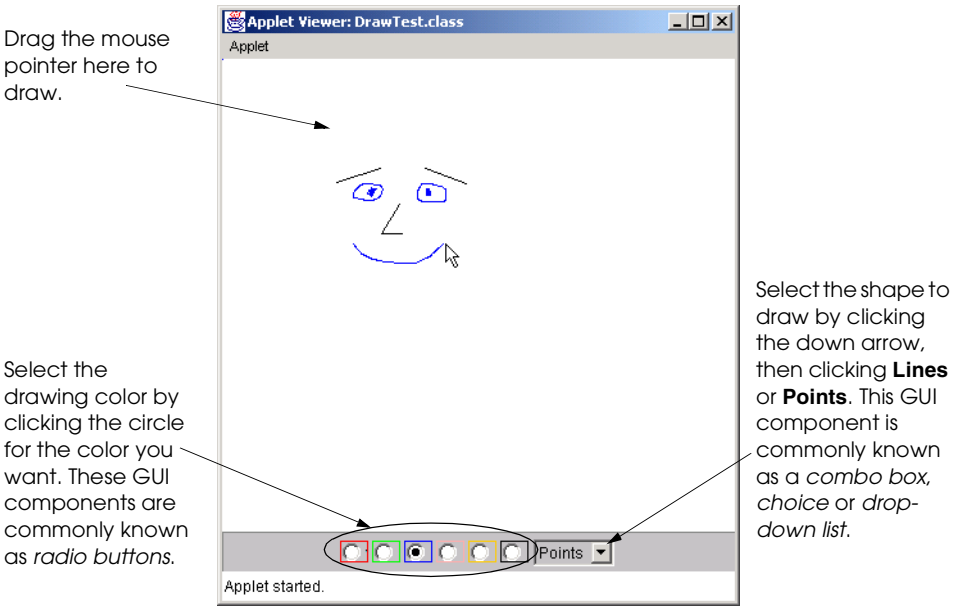

Fig. 3.4 Sample execution of applet **`DrawTest`**.

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Try changing the shape to draw from **Lines** to **Points** by clicking the down arrow to the right of the word **Lines** at the bottom of the applet. A list drops down from the GUI component containing the two choices—**Lines** and **Points**. To select **Points**, click the word **Points** in the list. The GUI component closes the list and the current shape type is now **Points**. This GUI component is commonly known as a *choice*, *combo box* or *drop-down list*.

To start a new drawing, select **Reload** from the **appletviewer**'s **Applet** menu. To terminate the applet, select **Quit** from the **appletviewer**'s **Applet** menu.

3.2.3 The Java2D Applet

The last applet we demonstrate before defining applets of our own shows many of the complex new two-dimensional drawing capabilities built into Java 2—known as the *Java2D API*. For this example, change directories to the **jfc** directory in the J2SDK's **demo** directory, then change to the **Java2D** directory (you can move up the directory tree toward **demo** using the command "**cd ..**" in both Windows and UNIX/Linux). In that directory is an HTML file (**Java2Demo.html**) that is used to execute the applet. In the command window, type the command

```
appletviewer Java2Demo.html
```

and press the *Enter* key. This executes the **appletviewer**. The **appletviewer** loads the HTML file specified as its command-line argument (**Java2Demo.html**), determines from the file which applet to load and begins execution of the applet. This particular demo takes some time to load as it is quite large. Figure 3.5 shows a screen capture of one of this applet's many demonstrations of Java's two-dimensional graphics capabilities.

At the top of this demo you see tabs that look like file folders in a filing cabinet. This demo provides 12 different tabs with several different features on each tab. To change to a different part of the demo, simply click one of the tabs. Also, try changing the options in the upper-right corner of the applet. Some of these affect the speed with which the applet draws the graphics. For example, click the small box with a check in it (a GUI component known as a *checkbox*) to the left of the word **Anti-Aliasing** to turn off anti-aliasing (a graphics technique for producing smoother on-screen graphics in which the edges of the graphic are blurred). When this feature is turned off (i.e., its *checkbox* is unchecked), the animation speed increases for the animated shapes at the bottom of the demo shown in Fig. 3.5. This occurs because an animated shape displayed with anti-aliasing takes longer to draw than an animated shape without anti-aliasing.

3.3 A Simple Java Applet: Drawing a String

Now, let's get started with some applets of our own. Remember, we are just getting started—we have many more topics to learn before we can write applets similar to those demonstrated in Section 3.2. However, we will cover many of the same techniques in this book.

We begin by considering a simple applet that mimics the program of Fig. 2.1 by displaying the string **"Welcome to Java Programming!"**. The applet and its screen output are shown in Fig. 3.6. The HTML document to load the applet into the **appletviewer** is shown and discussed in Fig. 3.7.

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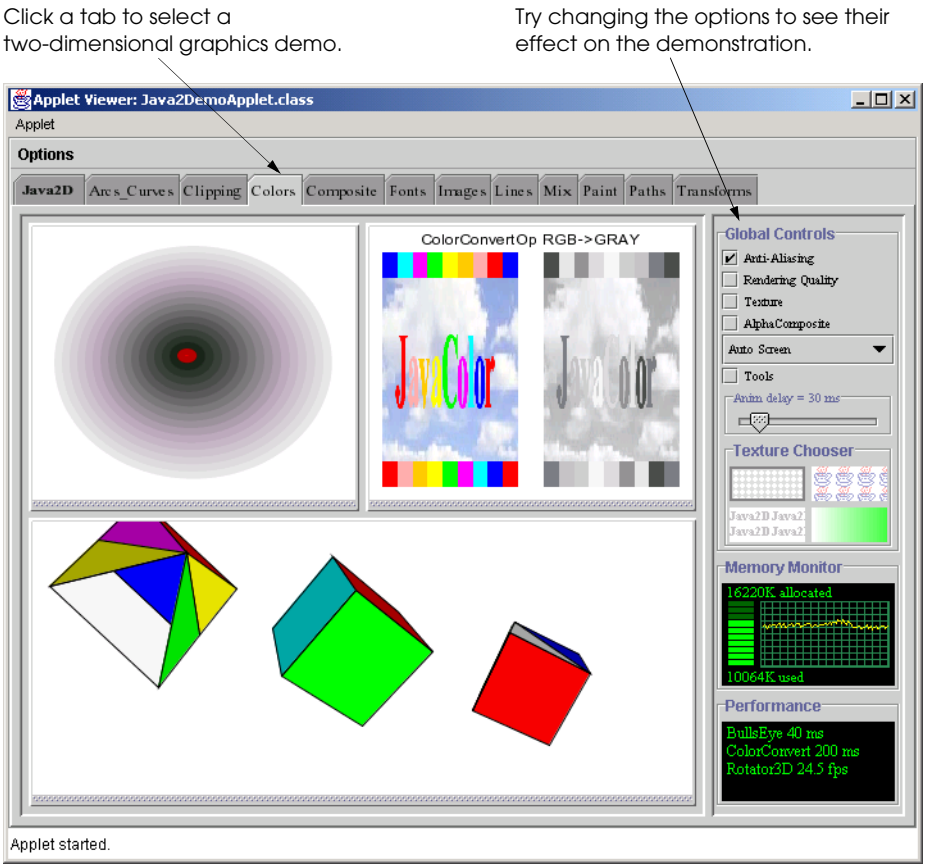

Fig. 3.5 Sample execution of applet **Java2D**.

```
1  // Fig. 3.6: WelcomeApplet.java
2  // A first applet in Java.
3
4  // Java core packages
5  import java.awt.Graphics;    // import class Graphics
6
7  // Java extension packages
8  import javax.swing.JApplet;  // import class JApplet
9
10 public class WelcomeApplet extends JApplet {
11
12    // draw text on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
```

Fig. 3.6 A first applet in Java and the applet's screen output (part 1 of 2).

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```
17
18          // draw a String at x-coordinate 25 and y-coordinate 25
19          g.drawString( "Welcome to Java Programming!", 25, 25 );
20
21       }  // end method paint
22
23    }  // end class WelcomeApplet
```

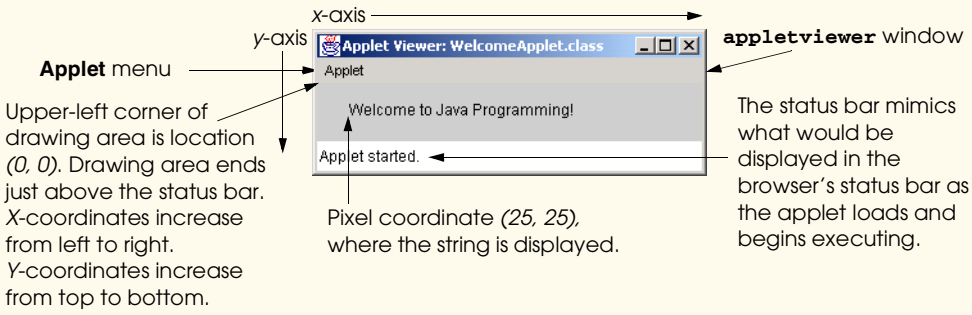

Fig. 3.6 A first applet in Java and the applet's screen output (part 2 of 2).

This program illustrates several important Java features. We consider each line of the program in detail. Line 19 does the "real work" of the program, namely drawing the string **`Welcome to Java Programming!`** on the screen. But let us consider each line of the program in order. Lines 1–2

```
// Fig. 3.6: WelcomeApplet.java
// A first applet in Java.
```

begin with **`//`**, indicating that the remainder of each line is a comment. The comment on line 1 indicates the figure number and file name for the applet source code. The comment on line 2 simply describes the purpose of the program.

As stated in Chapter 2, Java contains many predefined components called classes that are grouped into packages in the Java API. Line 5

```
import java.awt.Graphics;     // import class Graphics
```

is an **`import`** statement that tells the compiler load class ***`Graphics`*** from package ***`java.awt`*** for use in this Java applet. Class **`Graphics`** enables a Java applet to draw graphics such as lines, rectangles, ovals and strings of characters. Later in the book, you will see that class **`Graphics`** also enables applications to draw.

Line 8

```
import javax.swing.JApplet;  // import class JApplet
```

is an **`import`** statement that tells the compiler load class ***`JApplet`*** from package **`javax.swing`**. When you create an applet in Java, you normally import the **`JApplet`** class. [*Note:* There is an older class called ***`Applet`*** from package ***`java.applet`*** that is not used with Java's newest GUI components from the **`javax.swing`** package. In this book, we use only class **`JApplet`** with applets.]

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As with applications, every Java applet you create contains at least one class definition. One key feature of class definitions that was not mentioned in Chapter 2 is that programmers rarely create class definitions "from scratch." In fact, when you create a class definition, you normally use pieces of an existing class definition. Java uses *inheritance* (introduced in Section 1.15 and discussed in detail in Chapter 9, "Object-Oriented Programming") to create new classes from existing class definitions. Line 10

```
public class WelcomeApplet extends JApplet {
```

begins a **`class`** definition for class **`WelcomeApplet`**. At the end of line 10, the left brace, **`{`**, begins the body of the class definition. The corresponding right brace, **`}`**, on line 23 ends the class definition. Keyword **`class`** introduces the class definition. **`WelcomeApplet`** is the class name. Keyword ***`extends`*** indicates that class **`WelcomeApplet`** inherits existing pieces from another class. The class from which **`WelcomeApplet`** inherits (**`JApplet`**) appears to the right of **`extends`**. In this inheritance relationship, **`JApplet`** is called the *superclass* or *base class* and **`WelcomeApplet`** is called the *subclass* or *derived class*. Using inheritance here results in a **`WelcomeApplet`** class definition that has the *attributes* (data) and *behaviors* (methods) of class **`JApplet`** as well as the new features we are adding in our **`WelcomeApplet`** class definition (specifically, the ability to draw **`Welcome to Java Programming!`** on the applet).

A key benefit of extending class **`JApplet`** is that someone else previously defined "what it means to be an applet." The **`appletviewer`** and World Wide Web browsers that support applets expect every Java applet to have certain capabilities (attributes and behaviors). Class **`JApplet`** already provides all those capabilities—programmers do not need to "reinvent the wheel" and define all these capabilities on their own. In fact, applet containers expect applets to have over 200 different methods. In our programs to this point, we defined one method in each program. If we had to define over 200 methods just to display **`Welcome to Java Programming!`**, we would never create an applet, because it would take too long to define one! Using **`extends`** to inherit from class **`JApplet`** enables applet programmers to create new applets quickly.

The inheritance mechanism is easy to use; the programmer does not need to know every detail of class **`JApplet`** or any other superclass from which a new class inherits. The programmer needs to know only that class **`JApplet`** defines the capabilities required to create the minimum applet. However, to make the best use of any class, programmers should study all the capabilities of the superclass.

Good Programming Practice 3.1

*Investigate the capabilities of any class in the Java API documentation (**`java.sun.com/j2se/1.3/docs/api/index.html`**) carefully before inheriting a subclass from it. This helps ensure that the programmer does not unintentionally "reinvent the wheel" by redefining a capability that the superclass already provides.*

Classes are used as "templates" or "blueprints" to *instantiate* (or *create*) *objects* for use in a program. An object (or *instance*) resides in the computer's memory and contains information used by the program. The term object normally implies that attributes (data) and behaviors (methods) are associated with the object. The object's methods use the attributes to provide useful services to the *client of the object* (i.e., the code in a program that calls the methods).

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When an applet container (the **appletviewer** or browser in which the applet executes) loads our **WelcomeApplet** class, the applet container creates an object (instance) of class **WelcomeApplet** that implements the applet's attributes and behaviors. [*Note:* The terms instance and object are often used interchangeably.] Applet containers can create only objects of classes that are **public** and extend **JApplet**. Thus, applet containers require applet class definitions to begin with the keyword **public** (line 10). Otherwise, the applet container cannot load and execute the applet. The **public** keyword and related keywords (such as **private** and **protected**) are discussed in detail in Chapter 8, "Object-Based Programming." For now, we ask you simply to start all class definitions with the **public** keyword until the discussion of **public** in Chapter 8.

When you save a **public** class in a file, the file name must be the class name followed by the **.java** file name extension. For our applet, the file name must be **WelcomeApplet.java**. Please note that the class name part of the file name must use the same spelling as the class name, including identical use of uppercase and lowercase letters. For reinforcement, we repeat two Common Programming Errors from Chapter 2.

Common Programming Error 3.1

*It is an error for a **public** class if the file name is not identical to the class name (plus the **.java** extension) in both spelling and capitalization. Therefore, it is also an error for a file to contain two or more **public** classes.*

Common Programming Error 3.2

*It is an error not to end a file name with the **.java** extension for a file containing an application's class definition. The Java compiler will not be able to compile the class definition.*

Testing and Debugging Tip 3.4

*The compiler error message "Public class ClassName must be defined in a file called ClassName.java" indicates either that the file name does not exactly match the name of the **public** class in the file (including all uppercase and lowercase letters) or that you typed the class name incorrectly when compiling the class (the name must be spelled with the proper uppercase and lowercase letters).*

Line 13

```
public void paint( Graphics g )
```

begins the definition of the applet's ***paint*** *method*—one of three methods (behaviors) that the applet container calls for an applet when the container begins executing the applet. In order, these three methods are ***init*** (discussed later in this chapter), ***start*** (discussed in Chapter 6) and **paint**. Your applet class gets a "free" version of each of these methods from class **JApplet** when you specify **extends JApplet** in the first line of your applet's class definition. If you do not define these methods in your own applet, the applet container calls the versions inherited from **JApplet**. The inherited versions of methods **init** and **start** have empty bodies (i.e., their bodies do not contain statements, so they do not perform a task) and the inherited version of method **paint** does not draw anything on the applet. [*Note:* There are several other methods that an applet container calls during an applet's execution. We discuss these methods in Chapter 6, "Methods."]

To enable our applet to draw, class **WelcomeApplet** *overrides* (*replaces* or *redefines*) the default version of **paint** by placing statements in the body of **paint** that draw

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a message on the screen. When the applet container tells the applet to "draw itself" on the screen by calling method **paint**, our message **Welcome to Java Programming!** appears rather than a blank screen.

Lines 13–21 are the definition of **paint**. The task of method **paint** is to draw graphics (such as lines, ovals and strings of characters) on the screen. Keyword **void** indicates that this method does not return any results when it completes its task. The set of parentheses after **paint** defines the method's *parameter list*. The parameter list is where methods receive data required to perform their tasks. Normally, this data is passed by the programmer to the method through a *method call* (also known as *invoking a method* or *sending a message*). For example, in Chapter 2 we passed data to **JOptionPane**'s **showMessageDialog** method such as the message to display or the type of dialog box. However, when writing applets, the programmer does not call method **paint** explicitly. Rather, the applet container calls **paint** to tell the applet to draw and the applet container passes to the **paint** method the information **paint** requires to perform its task, namely a **Graphics** object (called **g**). It is the applet container's responsibility to create the **Graphics** object to which **g** refers. Method **paint** uses the **Graphics** object to draw graphics on the applet. The **public** keyword at the beginning of line 13 is required so the applet container can call your **paint** method. For now, all method definitions should begin with the **public** keyword. We introduce other alternatives in Chapter 8.

The left brace, **{**, on line 14 begins method **paint**'s body. The corresponding right brace, **}**, on line 21 ends **paint**'s body.

Line 16

```
super.paint( g );
```

calls the version of method **paint** inherited from superclass **JApplet**.[1]

Line 19

```
g.drawString( "Welcome to Java Programming!", 25, 25 );
```

instructs the computer to perform an action (or task), namely to draw the characters of the string **Welcome to Java Programming!** on the applet. This statement uses method **drawString** defined by class **Graphics** (this class defines all the drawing capabilities of a Java program, including strings of characters and shapes such as rectangles, ovals and lines). The statement calls method **drawString** using the **Graphics** object **g** (in **paint**'s parameter list) followed by a *dot operator* (**.**) followed by the method name **drawString**. The method name is followed by a set of parentheses containing the argument list **drawString** needs to perform its task.

The first argument to **drawString** is the **String** to draw on the applet. The last two arguments in the list—**25** and **25**—are the *x-y coordinates* (or *position*) at which the bottom-left corner of the string should be drawn on the applet. Drawing methods from class **Graphics** require coordinates to specify where to draw on the applet (later in the text we

1. For reasons that will become clear later in the text, this statement should be the first statement in every applet's **paint** method. Although the early examples of applets will work without this statement, omitting this statement causes subtle errors in more elaborate applets that combine drawing and GUI components. Including this statement now will get you in the habit of using it and will save time and effort as you build more substantial applets later.

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demonstrate drawing in applications). The first coordinate is the *x-coordinate* (the number of pixels from the left side of the applet), and the second coordinate is the *y-coordinate* (representing the number of pixels from the top of the applet). Coordinates are measured from the upper-left corner of the applet in *pixels* (just below the **Applet** menu in the sample output window of Fig. 3.6). A pixel ("picture element") is the unit of display for your computer's screen. On a color screen, a pixel appears as one colored dot on the screen. Many personal computers have 800 pixels for the width of the screen and 600 pixels for the height of the screen, for a total of 800 times 600 or 480,000 displayable pixels. Many computers today have screens with higher screen resolutions, i.e., they have more pixels for the width and height of the screen. The size of an applet on the screen depends on the size and resolution of the screen. For screens with the same size, the applet will appear smaller on the screen with the higher resolution. Note that some older computers have screen resolutions lower than 800 by 600. The most common lower resolution is 640 by 480.

When line 19 executes, it draws the message **`Welcome to Java Programming!`** on the applet at the coordinates **`25`** and **`25`**. Note that the quotation marks enclosing the string are *not* displayed on the screen.

As an aside, why would you want free copies of methods **`init`**, **`start`** and **`paint`** if they do not perform a task? The predefined start-up sequence of method calls made by the **`appletviewer`** or browser for every applet is always **`init`**, **`start`** and **`paint`**—this provides an applet programmer a guarantee that these methods will be called as every applet begins execution. Every applet does not need all three of these methods. However, the **`appletviewer`** or browser expects each of these methods to be defined so it can provide a consistent start-up sequence for an applet. [Note: This is similar to applications always starting execution with **`main`**.] Inheriting the default versions of these methods guarantees the browser that it can treat each applet uniformly by calling **`init`**, **`start`** and **`paint`** as applet execution begins. Also, the programmer can concentrate on defining only the methods required for a particular applet.

3.3.1 Compiling and Executing `WelcomeApplet`

As with application classes, you must compile applet classes before they can execute. After defining class **`WelcomeApplet`** and saving it in **`WelcomeApplet.java`**, open a command window, change to the directory in which you saved the applet class definition and type the command

```
javac WelcomeApplet.java
```

to compile class **`WelcomeApplet`**. If there are no syntax errors, the resulting bytecodes are stored in the file **`WelcomeApplet.class`**.

Before you can execute the applet you must create an *HTML (Hypertext Markup Language)* file to load the applet into the applet container (**`appletviewer`** or a browser). Typically, an HTML file ends with the "***`.html`***" or "***`.htm`***" file name extension. Browsers display the contents of documents that contain text (also known as *text files*). To execute a Java applet, an HTML text file must indicate which applet the applet container should load and execute. Figure 3.7 shows a simple HTML file—**`WelcomeApplet.html`**—that loads into the applet defined in Fig. 3.6 into an applet container. [Note: For the early part of this book, we always demonstrate applets with the **`appletviewer`** applet container.]

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```
1  <html>
2  <applet code = "WelcomeApplet.class" width = "300" height = "45">
3  </applet>
4  </html>
```

Fig. 3.7 **WelcomeApplet.html** loads class **WelcomeApplet** of Fig. 3.6 into the **appletviewer**.

Good Programming Practice 3.2

Always test a Java applet in the ***appletviewer*** *and ensure that it is executing correctly before loading the applet into a World Wide Web browser. Browsers often save a copy of an applet in memory until the current browsing session terminates (i.e., all browser windows are closed). Thus, if you change an applet, recompile the applet, then reload the applet in the browser, you may not see the changes because the browser may still be executing the original version of the applet. Close all your browser windows to remove the old version of the applet from memory. Open a new browser window and load the applet to see your changes.*

Software Engineering Observation 3.1

If your World Wide Web browser does not support Java 2, most of the applets in this book will not execute in your browser. This is because most of the applets in this book use features that are specific to Java 2 or are not provided by browsers that support Java 1.1. Section 3.6.2 discusses how to use the Java Plug-in to view applets in Web browsers that do not support Java 2.

Many HTML codes (or *tags*) come in pairs. For example, lines 1 and 4 of Fig. 3.7 indicate the beginning and the end, respectively, of the HTML tags in the file. All HTML tags begin with a *left angle bracket,* **<**, and end with a *right angle bracket,* **>**. Lines 2 and 3 are special HTML tags for Java applets. They tell the applet container to load a specific applet and define the size of the applet's display area (its *width* and *height* in pixels) in the **appletviewer** (or browser). Normally, the applet and its corresponding HTML file are stored in the same directory on disk. Typically, a browser loads an HTML file from a computer (other than your own) connected to the Internet. However, HTML files also can reside on your computer (as we demonstrated in Section 3.2). When an applet container encounters an HTML file that specifies an applet to execute, the applet container automatically loads the applet's **.class** file (or files) from the same directory on the computer in which the HTML file resides.

The ***<applet>*** *tag* has several *attributes*. The first attribute of the **<applet>** tag on line 2 (**code = "WelcomeApplet.class"**) indicates that the file **WelcomeApplet.class** contains the compiled applet class. Remember, when you compile your Java programs, every class is compiled into a separate file that has the same name as the class and ends with the **.class** extension. The second and third attributes of the **<applet>** tag indicate the ***width*** and the ***height*** of the applet in pixels. The upper-left corner of the applet's display area is always at *x*-coordinate 0 and *y*-coordinate 0. The width of this applet is 300 pixels and its height is 45 pixels. You may want (or need) to use larger **width** and **height** values to define a larger drawing area for your applets. The **</applet>** tag (line 3) terminates the **<applet>** tag that began on line 2. The **</html>** tag (line 4) specifies the end of the HTML tags that began on line 1 with **<html>**.

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Software Engineering Observation 3.2

Generally, each applet should be less than 800 pixels wide and 600 pixels tall (most computer screens support these dimensions as the minimum width and height).

Common Programming Error 3.3

*Placing additional characters such as commas (**,**) between the attributes in the **<applet>** tag may cause the **appletviewer** or browser to produce an error message indicating a **MissingResourceException** when loading the applet.*

Common Programming Error 3.4

*Forgetting the ending **</applet>** tag prevents the applet from loading into the **appletviewer** or browser properly.*

Testing and Debugging Tip 3.5

*If you receive a **MissingResourceException** error message when loading an applet into the **appletviewer** or a browser, check the **<applet>** tag in the HTML file carefully for syntax errors. Compare your HTML file to the file in Fig. 3.7 to confirm proper syntax.*

The **appletviewer** understands only the **<applet>** and **</applet>** HTML tags, so it is sometimes referred to as the "minimal browser" (it ignores all other HTML tags). The **appletviewer** is an ideal place to test an applet and ensure that it executes properly. Once the applet's execution is verified, you can add the applet's HTML tags to an HTML file that will be viewed by people browsing the Internet.

To execute the **WelcomeApplet** in the **appletviewer** open a command window, change to the directory containing your applet and HTML file and type the command

```
appletviewer WelcomeApplet.html
```

Note that the **appletviewer** *requires* an HTML file to load an applet. This is different from the **java** interpreter for applications which requires only the class name of the application class. Also, the preceding command must be issued from the directory in which the HTML file and the applet's **.class** file are located.

Common Programming Error 3.5

*Running the **appletviewer** with a file name that does not end with **.html** or **.htm** is an error that prevents the **appletviewer** from loading your applet for execution.*

Portability Tip 3.2

Test your applets in every browser used by people who view your applet. This will help ensure that people who view your applet experience the functionality you expect. [Note: A goal of the Java Plug-In (discussed later in the book) is to provide consistent applet execution across many different browsers.]

3.4 Two More Simple Applets: Drawing Strings and Lines

Let us consider another applet. An applet can draw **Welcome to Java Programming!** several ways. For example, an applet can use two **drawString** statements in method **paint** to print multiple lines of text as in Fig. 3.8. The HTML file to load the applet into an applet container is shown in Fig. 3.9.

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```
1  // Fig. 3.8: WelcomeApplet2.java
2  // Displaying multiple strings in an applet.
3
4  // Java core packages
5  import java.awt.Graphics;    // import class Graphics
6
7  // Java extension packages
8  import javax.swing.JApplet;  // import class JApplet
9
10 public class WelcomeApplet2 extends JApplet {
11
12    // draw text on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
17
18       // draw two Strings at different locations
19       g.drawString( "Welcome to", 25, 25 );
20       g.drawString( "Java Programming!", 25, 40 );
21
22    }  // end method paint
23
24 }  // end class WelcomeApplet2
```

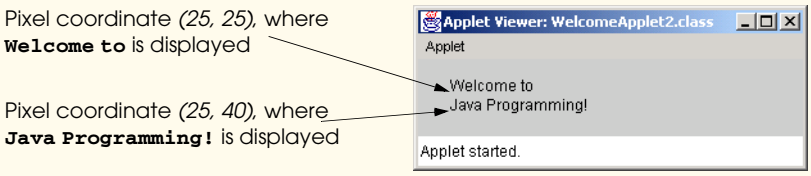

Fig. 3.8 Applet that displays multiple strings.

```
1  <html>
2  <applet code = "WelcomeApplet2.class" width = "300" height = "60">
3  </applet>
4  </html>
```

Fig. 3.9 **WelcomeApplet2.html** loads class **WelcomeApplet2** of Fig. 3.8 into the **appletviewer**.

Note that each call to method **drawString** can draw at any pixel location on the applet. The reason the two output lines appear left aligned as shown in Fig. 3.8 is that both use the same *x* coordinate (**25**). Also, each **drawString** method call uses different *y* coordinates (**25** on line 19 and **40** on line 20), so the strings appear at different vertical locations on the applet. If we reverse lines 19 and 20 in the program, the output window will still appear as shown because the pixel coordinates specified in each **drawString** statement are independent of the coordinates specified in all other **drawString** statements (and all other drawing operations). When drawing graphics, lines of text are not separated by newline characters (as shown with methods **System.out**'s method **println** and **JOptionPane**'s method **showMessageDialog** in Chapter 2). In fact, if you try

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to output a string containing a newline character (**\n**), you will simply see a small black box at that position in the string.

To make drawing more interesting, the applet of Fig. 3.10 draws two lines and a string. The HTML file to load the applet into an applet container is shown in Fig. 3.11.

```
1  // Fig. 3.10: WelcomeLines.java
2  // Displaying text and lines
3
4  // Java core packages
5  import java.awt.Graphics;    // import class Graphics
6
7  // Java extension packages
8  import javax.swing.JApplet;  // import class JApplet
9
10 public class WelcomeLines extends JApplet {
11
12    // draw lines and a string on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
17
18       // draw horizontal line from (15, 10) to (210, 10)
19       g.drawLine( 15, 10, 210, 10 );
20
21       // draw horizontal line from (15, 30) to (210, 30)
22       g.drawLine( 15, 30, 210, 30 );
23
24       // draw String between lines at location (25, 25)
25       g.drawString( "Welcome to Java Programming!", 25, 25 );
26
27    }  // end method paint
28
29 }  // end class WelcomeLines
```

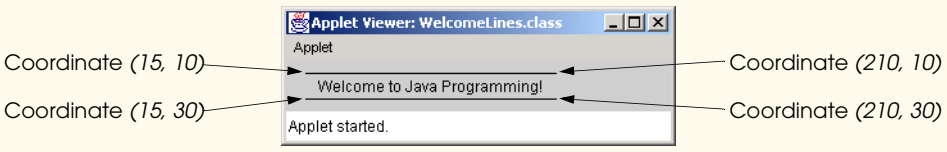

Fig. 3.10 Drawing strings and lines.

```
1  <html>
2  <applet code = "WelcomeLines.class" width = "300" height = "40">
3  </applet>
4  </html>
```

Fig. 3.11 The **WelcomeLines.html** file, which loads class **WelcomeLines** of Fig. 3.10 into the **appletviewer**.

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Lines 19 and 22 of method **paint**

```
g.drawLine( 15, 10, 210, 10 );
g.drawLine( 15, 30, 210, 30 );
```

use *method* ***drawLine*** of class **Graphics** to indicate that the **Graphics** object that **g** refers to should draw lines. Method **drawLine** requires four arguments that represent the two end points of the line on the applet—the *x*-coordinate and *y*-coordinate of the first end point in the line and the *x*-coordinate and *y*-coordinate of the second end point in the line. All coordinate values are specified with respect to the upper-left corner *(0, 0)* coordinate of the applet. Method **drawLine** draws a straight line between the two end points.

3.5 Another Java Applet: Adding Floating-Point Numbers

Our next applet (Fig. 3.12) mimics the application of Fig. 2.9 for adding two integers. However, this applet requests that the user enter two *floating-point numbers* (i.e., numbers with a decimal point such as 7.33, 0.0975 and 1000.12345). To store floating-point numbers in memory we introduce primitive data type ***double***, which represents *double-precision floating-point* numbers. There is also primitive data type ***float*** for *storing single-precision floating-point* numbers. A **double** requires more memory to store a floating-point value, but stores it with approximately twice the precision of a **float** (15 significant digits for **double** vs. seven significant digits for **float**).

Once again, we use **JOptionPane.showInputDialog** to request input from the user. The applet computes the sum of the input values and displays the result by drawing a string inside a rectangle on the applet. The HTML file to load this applet into the **appletviewer** is shown in Fig. 3.13.

```
1  // Fig. 3.12: AdditionApplet.java
2  // Adding two floating-point numbers.
3
4  // Java core packages
5  import java.awt.Graphics;   // import class Graphics
6
7  // Java extension packages
8  import javax.swing.*;       // import package javax.swing
9
10 public class AdditionApplet extends JApplet {
11    double sum;  // sum of values entered by user
12
13    // initialize applet by obtaining values from user
14    public void init()
15    {
16       String firstNumber;   // first string entered by user
17       String secondNumber;  // second string entered by user
18       double number1;       // first number to add
19       double number2;       // second number to add
20
21       // obtain first number from user
22       firstNumber = JOptionPane.showInputDialog(
23          "Enter first floating-point value" );
```

Fig. 3.12 An addition program "in action" (part 1 of 2).

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```
24
25          // obtain second number from user
26          secondNumber = JOptionPane.showInputDialog(
27             "Enter second floating-point value" );
28
29          // convert numbers from type String to type double
30          number1 = Double.parseDouble( firstNumber );
31          number2 = Double.parseDouble( secondNumber );
32
33          // add numbers
34          sum = number1 + number2;
35       }
36
37       // draw results in a rectangle on applet's background
38       public void paint( Graphics g )
39       {
40          // call inherited version of method paint
41          super.paint( g );
42
43          // draw rectangle starting from (15, 10) that is 270
44          // pixels wide and 20 pixels tall
45          g.drawRect( 15, 10, 270, 20 );
46
47          // draw results as a String at (25, 25)
48          g.drawString( "The sum is " + sum, 25, 25 );
49
50       }  // end method paint
51
52    }  // end class AdditionApplet
```

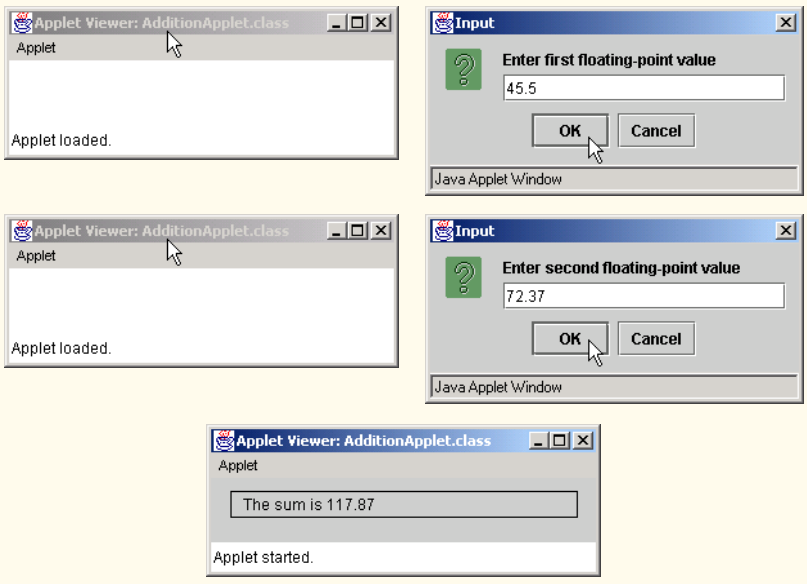

Fig. 3.12 An addition program "in action" (part 2 of 2).

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```
1  <html>
2  <applet code = "AdditionApplet.class" width = "300" height = "65">
3  </applet>
4  </html>
```

Fig. 3.13 **AdditionApplet.html** loads class **AdditionApplet** of Fig. 3.12 into the **appletviewer**.

Lines 1–2

```
// Fig. 3.12: AdditionApplet.java
// Adding two floating-point numbers.
```

are single-line comments stating the figure number, file name and purpose of the program.

Line 5

```
import java.awt.Graphics;    // import class Graphics
```

imports class **Graphics** (package **java.awt**) for use in this applet. Actually, the **import** statement at line 5 is not required if we always use the complete name of class **Graphics**—***java.awt.Graphics***—which includes the full package name and class name. For example, the first line of method **paint** can be defined as

```
public void paint( java.awt.Graphics g )
```

Software Engineering Observation 3.3

The Java compiler does not require ***import*** *statements in a Java source code file if the complete class name—the full package name and class name (e.g.,* ***java.awt.Graphics****)—is specified every time a class name is used in the source code.*

Line 8

```
import javax.swing.*;        // import package javax.swing
```

specifies to the compiler that several classes from package **javax.swing** are used in this applet. The asterisk (*) indicates that all classes in the **javax.swing** package (such as **JApplet** and **JOptionPane**) should be available to the compiler so the compiler can ensure that we use the classes correctly. This allows programmers to use the *shorthand name* (the class name by itself) of any class from the **javax.swing** package in the program. Remember that our last two programs imported only class **JApplet** from package **javax.swing**. In this program, we use classes **JApplet** and **JOptionPane** from that package. Importing an entire package into a program is also a shorthand notation so the programmer is not required to provide a separate **import** statement for every class used from that package. Remember that you can always use the complete name of every class, i.e., **javax.swing.JApplet** and **javax.swing.JOptionPane** rather than **import** statements.

Software Engineering Observation 3.4

The compiler does not load every class in a package when it encounters an ***import*** *statement that uses the* ***** *(e.g.,* ***javax.swing.****) notation. The compiler loads from the package only those classes the program uses.*

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Software Engineering Observation 3.5

Many packages have subpackages. For example, the **`java.awt`** *package has subpackage* **`event`** *for the package* **`java.awt.event`**. *When the compiler encounters an* **`import`** *statement that uses the* **`*`** *(e.g.,* **`java.awt.*`***) notation to indicate that a program uses multiple classes from a package, the compiler does not load classes from the subpackage* **`event`**. *Thus, you cannot define an* **`import`** *of* **`java.*`** *to search for classes from all Java core packages.*

Software Engineering Observation 3.6

When using **`import`** *statements, separate* **`import`** *statements must be specified for each package used in a program.*

Common Programming Error 3.6

Assuming that an **`import`** *statement for an entire package (e.g.,* **`java.awt.*`***) also* **`import`***s classes from subpackages in that package (e.g.,* **`java.awt.event.*`***) results in syntax errors for the classes from the subpackages. There must be separate import statements for every package from which classes are used.*

Remember that applets inherit from the **`JApplet`** class, so they have all the methods that an applet container requires to execute the applet. Line 10

```
public class AdditionApplet extends JApplet {
```

begins class **`AdditionApplet`**'s definition and indicates that it inherits from **`JApplet`**.

All class definitions start with an opening left brace (end of line 10), **`{`**, and end with a closing right brace, **`}`** (line 52).

Common Programming Error 3.7

If braces do not occur in matching pairs, the compiler indicates a syntax error.

Line 11

```
double sum;  // sum of values entered by user
```

is an *instance variable declaration*—every instance (object) of the class contains one copy of each instance variable. For example, if there are 10 instances of this applet executing, each instance has its own copy of **`sum`**. Thus, there would be 10 separate copies of **`sum`** (one per applet). Programmers declare instance variables in the body of the class definition, but outside the bodies of all the class's method definitions. The preceding declaration states that **`sum`** is a variable of primitive type **`double`**.

A benefit of instance variables is that all the methods of the class can use the instance variables. Until now, we declared all variables in an application's **`main`** method. Variables defined in the body of a method are known as *local variables* and can be used only in the body of the method in which they are defined. Another distinction between instance variables and local variables is that instance variables have default values and local variables do not. The default value of variable **`sum`** is 0.0, because **`sum`** is an instance variable.

Good Programming Practice 3.3

Explicitly initializing instance variables rather than relying on automatic initialization improves program readability.

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The applet of Fig. 3.12 contains two methods—**init** (lines 14–35) and **paint** (lines 38–50). When an applet container loads an applet, the container creates an instance of the applet class and calls its **init** method. The applet container calls method **init** only once during an applet's execution. Method **init** normally *initializes* the applet's instance variables (if they need to be initialized to a value other than their default value) and performs tasks that should occur only once when the applet begins execution. As we will see in later chapters, the applet's **init** method typically creates the applet's graphical user interface.

Software Engineering Observation 3.7

The order in which methods are defined in a class definition has no effect on when those methods are called at execution time. However, following conventions for the order in which methods are defined improves program readability and maintainability.

The first line of the **init** method always appears as

```
public void init()
```

indicating that **init** is a **public** method that returns no information (**void**) when it completes and receives no arguments (empty parentheses after **init**) to perform its task.

The left brace (line 15) marks the beginning of **init**'s body, and the corresponding right brace (line 35) marks the end of **init**. Lines 16–17

```
String firstNumber;    // first string entered by user
String secondNumber;   // second string entered by user
```

declare local **String** variables **firstNumber** and **secondNumber** in which the program stores the **String**s input by the user.

Lines 18–19

```
double number1;        // first number to add
double number2;        // second number to add
```

declare local variables **number1** and **number2** of primitive data type **double**—these variables hold floating-point values. Unlike **sum**, **number1** and **number2** are not instance variables, so they are not initialized to 0.0 (the default value of **double** instance variables).

As an important aside, there are actually two types of variables in Java—*primitive data type variables* (normally called *variables*) and *reference variables* (normally called *references*). The identifiers **firstNumber** and **secondNumber** are actually references—names that are used to *refer to objects* in the program. Such references actually contain the location of an object in the computer's memory. In our preceding applets, method **paint** actually receives a reference called **g** that refers to a **Graphics** object. Statements in method **paint** use that reference to send messages to the **Graphics** object. These messages are calls to methods (like **drawString**, **drawLine** and **drawRect**) that enable the program to draw. For example, the statement

```
g.drawString( "Welcome to Java Programming!", 25, 25 );
```

sends the **drawString** message to the **Graphics** object to which **g** refers. As part of the message, which is simply a method call, we provide the data that **drawString** re-

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quires to do its task. The **Graphics** object uses this data to draw the **String** at the specified location.

The identifiers **number1**, **number2** and **sum** are the names of *variables.* A variable is similar to an object. The primary difference between a variable and an object is that an object is defined by a class definition that can contain both data (instance variables) and methods, whereas a variable is defined by a *primitive (or built-in) data type* (one of **char**, **byte**, **short**, **int**, **long**, **float**, **double** or **boolean**) that can contain only data. A variable can store exactly one value at a time, whereas one object may contain many individual pieces of data. The distinction between a variable and a reference is based on the data type of the identifier, which is stated in a declaration. If the data type is a class name, the identifier is a reference to an object and that reference can be used to send messages to (call methods on) that object. If the data type is one of the primitive data types, the identifier is a variable that can be used to store in memory or retrieve from memory a single value of the declared primitive type.

Software Engineering Observation 3.8

A hint to help you determine if an identifier is a variable or a reference is the variable's data type. By convention all class names in Java start with a capital letter. Therefore, if the data type starts with a capital letter, normally you can assume that the identifier is a reference to an object of the declared type (e.g., ***Graphics g*** *indicates that* ***g*** *is a reference to a* ***Graphics*** *object).*

Lines 22–23

```
// obtain first number from user
firstNumber = JOptionPane.showInputDialog(
   "Enter first floating-point value" );
```

read the first floating-point number from the user. **JOptionPane** method **showInputDialog** displays an input dialog that prompts the user to enter a value. The user types a value in the input dialog's text field, then clicks the **OK** button to return the string the user typed to the program. If you type and nothing appears in the text field, position the mouse pointer in the text field and click the mouse to make the text field active. Variable **firstNumber** is assigned the result of the call to **JOptionPane.showInputDialog** operation with an assignment statement. The statement is read as "**firstNumber** *gets* the value of **JOptionPane.showInputDialog("Enter first floating-point value")**."

In lines 22–23, notice the method call syntax. At this point, we have seen two different ways to call methods. This statement uses the **static** method call syntax introduced in Chapter 2. All **static** methods are called with the syntax

ClassName.*methodName*(*arguments*)

Also in this chapter, we have called methods of class **Graphics** with a similar syntax that started with a reference to a **Graphics** object. Generically, this syntax is

referenceName.*methodName*(*arguments*)

This syntax is used for most methods calls in Java. In fact, the applet container uses this syntax to call methods **init**, **start** and **paint** on your applets.

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Lines 26–27

```
// obtain second number from user
secondNumber = JOptionPane.showInputDialog(
   "Enter second floating-point value" );
```

read the second floating-point value from the user by displaying an input dialog.

Lines 30–31

```
number1 = Double.parseDouble( firstNumber );
number2 = Double.parseDouble( secondNumber );
```

convert the two strings input by the user to **double** values for use in a calculation. Method ***Double.parseDouble*** (a **static** method of class **Double**) converts its **String** argument to a **double** floating-point value. Class **Double** is in package **java.lang**. The floating-point value returned by **parseDouble** in line 30 is assigned to variable **number1**. The floating-point value returned by **parseDouble** in line 31 is assigned to variable **number2**.

Software Engineering Observation 3.9

*Each primitive data type (such as **int** or **double**) has a corresponding class (such as **Integer** or **Double**) in package **java.lang**. These classes (commonly known as* type-wrapper classes*) provide methods for processing primitive data type values (such as converting a **String** to a primitive data type value or converting a primitive data type value to a **String**). Primitive data types do not have methods. Therefore, methods related to a primitive data type are located in the corresponding type-wrapper class (e.g., method **parseDouble** that converts a **String** to a **double** value is located in class **Double**). See the online API documentation for the complete details of the methods in the type-wrapper classes.*

The assignment statement at line 34

```
sum = number1 + number2;
```

calculates the sum of the values stored in variables **number1** and **number2** and assigns the result to variable **sum** using the assignment operator **=**. The statement is read as "**sum** *gets* the value of **number1 + number2**." Notice that instance variable **sum** is used in method **init** even though **sum** was not defined in method **init**. We can use **sum** in **init** (and all other methods of the class), because **sum** is an instance variable.

At this point the applet's **init** method returns and the applet container calls the applet's **start** method. We did not define **start** in this applet, so the one inherited from class **JApplet** is called here. Normally, the **start** method is used with an advanced concept called multithreading. See Chapter 15 and Chapter 18 for typical uses of **start**.

Next, the applet container calls the applet's **paint** method. In this example, method **paint** draws a rectangle in which the result of the addition will appear. Line 45

```
g.drawRect( 15, 10, 270, 20 );
```

sends the **drawRect** message to the **Graphics** object to which **g** refers (calls the **Graphics** object's **drawRect** method). Method **drawRect** draws a rectangle based on its four arguments. The first two integer values represent the *upper-left x-coordinate* and *upper-left y-coordinate* where the **Graphics** object begins drawing the rectangle. The third and fourth arguments are non-negative integers that represent the *width* of the rectan-

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gle in pixels and the *height* of the rectangle in pixels, respectively. This particular statement draws a rectangle starting at coordinate *(15, 10)* that is 270 pixels wide and 20 pixels tall.

Common Programming Error 3.8

It is a logic error to supply a negative width or negative height as an argument to **`Graphics`** *method* **`drawRect`***. The rectangle will not be displayed and no error will be indicated.*

Common Programming Error 3.9

It is a logic error to supply two points (i.e., pairs of x- and y-coordinates) as the arguments to **`Graphics`** *method* **`drawRect`***. The third argument must be the width in pixels and the fourth argument must be the height in pixels of the rectangle to draw.*

Common Programming Error 3.10

It is normally a logic error to supply arguments to **`Graphics`** *method* **`drawRect`** *that cause the rectangle to draw outside the applet's viewable area (i.e., the width and height of the applet as specified in the HTML document that references the applet). Either increase the applet's width and height in the HTML document or pass arguments to method* **`drawRect`** *that cause the rectangle to draw inside the applet's viewable area.*

Line 48

```
g.drawString( "The sum is " + sum, 25, 25 );
```

sends the **`drawString`** message to the **`Graphics`** object to which **`g`** refers (calls the **`Graphics`** object's **`drawString`** method). The expression

```
"The sum is " + sum
```

from the preceding statement uses the string concatenation operator **`+`** to concatenate the string **`"The sum is "`** and **`sum`** (converted to a string) to create the string **`drawString`** displays. Notice again that the preceding statement uses the instance variable **`sum`** even though method **`paint`** does not define **`sum`** as a local variable.

The benefit of defining **`sum`** as an instance variable is that we were able to assign **`sum`** a value in **`init`** and use **`sum`**'s value in the **`paint`** method later in the program. All methods of a class are capable of using the instance variables in the class definition.

Software Engineering Observation 3.10

The only statements that should be placed in an applet's **`init`** *method are those that are directly related to the one-time initialization of an applet's instance variables. The applet's results should be displayed from other methods of the applet class. Results that involve drawing should be displayed from the applet's* **`paint`** *method.*

Software Engineering Observation 3.11

The only statements that should be placed in an applet's **`paint`** *method are those that are directly related to drawing (i.e., calls to methods of class* **`Graphics`***) and the logic of drawing. Generally, dialog boxes should not be displayed from an applet's* **`paint`** *method.*

3.6 Viewing Applets in a Web Browser

We demonstrated several applets in this chapter using the **`appletviewer`** applet container. As we mentioned, applets also can execute in Java-enabled Web browsers. Unfortunate-

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ly, there are many different browser versions being used worldwide. Some support only Java 1.0 and many support Java 1.1. However, few support the Java 2 Platform. Also, even the browsers that support Java 1.1 do so inconsistently. In Section 3.6.1, we demonstrate an applet executing in Netscape Navigator 6, which supports Java 2. In Section 3.6.2, we demonstrate how to use the Java Plug-in to execute Java 2 applets in other Web browsers such as Microsoft Internet Explorer or earlier versions of Netscape Navigator.

Portability Tip 3.3

Not all Web browsers support Java. Those that do often support different versions and are not always consistent across all platforms.

3.6.1 Viewing Applets in Netscape Navigator 6

When you install Netscape Navigator 6, one of the browser components in the default installation is Java 2. Once installed, you can simply load an applet's HTML file into the browser to execute the applet. You can download and install Netscape 6 from

```
www.netscape.com
```

by clicking the **Download** button at the top of the Web page.

After installing the browser, open the program. On Windows, Netscape 6 typically places an icon on your desktop during the install process. In the **File** menu, click **Open File...** to select an HTML document from your local computer's hard disk. In the **Open File** dialog, navigate to the location of the HTML file of Fig. 3.11. Select the file name **`WelcomeLines.html`** by clicking it, then click the **Open** button to open the file in the browser. In a few moments, you should see the applet of Fig. 3.10 appear in the browser window as shown in Fig. 3.14.

3.6.2 Viewing Applets in Other Browsers Using the Java Plug-In

If you would like to use the features of the Java 2 platform in an applet and execute that applet in a browser that does not support Java 2, Sun provides the *Java Plug-in* to bypass a browser's Java support and use a complete version of the *Java 2 Runtime Environment (J2RE)* that is installed on the user's local computer. If the J2RE does not already exist on the client machine, it can be downloaded and installed dynamically.

Performance Tip 3.1

Because of the size of the Java Plug-in, it is difficult and inefficient to download the Plug-in for users with slower Internet connections. For this reason, the Plug-in is ideal for corporate intranets where users are connected to a high-speed network. Once the Plug-in is downloaded, it does not need to be downloaded again.

You must indicate in the HTML file containing an applet that the browser should use the Java Plug-in to execute the applet. To do so, requires that you convert the **`<applet>`** and **`</applet>`** tags into tags that load the Java Plug-in and execute the applet. Sun provides a conversion utility called the *Java Plug-in 1.3 HTML Converter*[2] that performs the conversion for you. Complete information on downloading and using the Java Plug-in and the HTML Converter are available at the Web site

```
java.sun.com/products/plugin/
```

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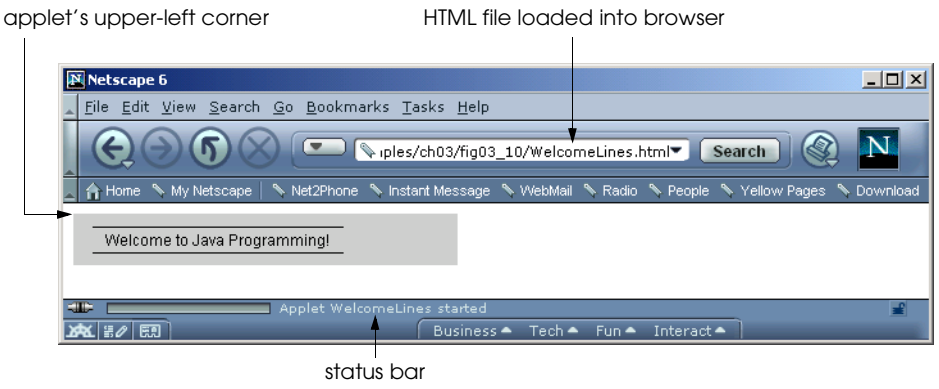

Fig. 3.14 Applet of Fig. 3.10 executing in Netscape Navigator 6.

Once you have downloaded and installed the Java Plug-in HTML converter, you can execute it via the batch file **`HTMLConverter.bat`** on Windows or the shell script **`HTMLConverter.sh`** on Linux/UNIX. These files are located in the **`converter`** directory's **`classes`** subdirectory. Figure 3.15 shows the **Java Plug in HTML Converter** window.

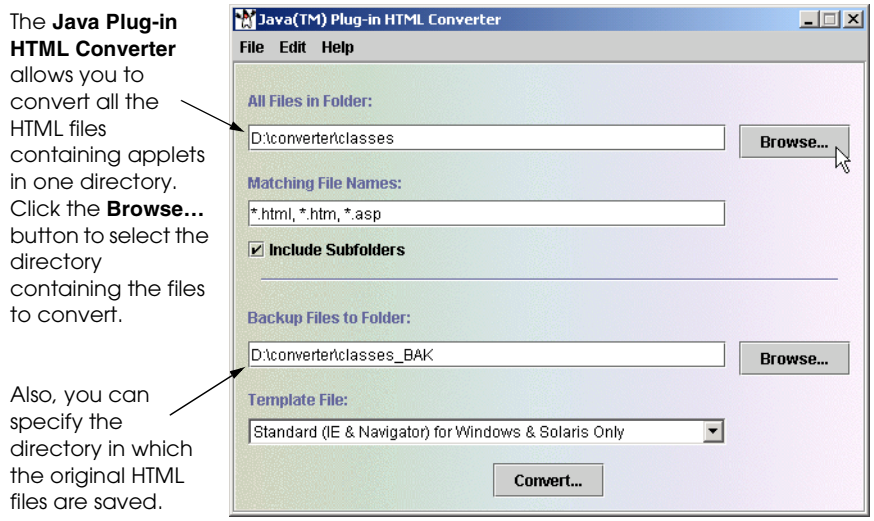

Fig. 3.15 **Java Plug-in HTML Converter** window.

2. As of Java 2 Software Development Kit version 1.3.1, a command-line version of the Java Plug-in HTML converter is one of the tools in the J2SDK. To use the command-line version, open a command window and change directories to the location that contains the HTML file to convert. In that directory type **`HTMLConverter`** *fileName*, where *fileName* is the HTML file to convert. Visit **`java.sun.com/products/plugin/1.3/docs/htmlconv.html`** for more details on the command-line HTML converter.

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To perform the conversion, you must select the directory containing the HTML files to convert. You can either type the directory name in the text field below **All Files in Folder**, or you can select the directory by clicking the **Browse...** button to the right of that text field. We clicked the **Browse...** button to display the **Open** dialog in Fig. 3.16.

After selecting the directory containing files to convert, the **Java Plug in HTML Converter** window appears as in Fig. 3.17. The converter provides several conversion templates to support different combinations of browsers. The default template supports Netscape Navigator and Microsoft Internet Explorer. Figure 3.17 shows the expanded ***Template File*** drop-down list containing the pre-defined conversion templates. We selected the default template that enables Microsoft Internet Explorer and Netscape Navigator to use the plug-in to execute an applet.

After selecting the appropriate template file, click the ***Convert...*** button at the bottom of the **Java Plug in HTML Converter** window. Figure 3.18 shows the dialog box that appears containing the status and results of the conversion. At this point the applet's HTML file can be loaded into Netscape Navigator or Microsoft Internet Explorer to execute the applet. If the Java 2 Runtime Environment does not already exist on the user's computer, the converted HTML file contains information that enables the browser to prompt users to determine if they would like to download the plug-in.

In this chapter and Chapter 2, we have introduced many important features of Java, including applications, applets, displaying data on the screen, inputting data from the keyboard, performing calculations and making decisions. In Chapter 4, we build on these techniques as we introduce *structured programming*. Here, you will become more familiar with indentation techniques. We also study how to specify and vary the order in which a program executes statements—this order is called *flow of control*.

The **Open** dialog box allows you to select the directory containing the files to convert.

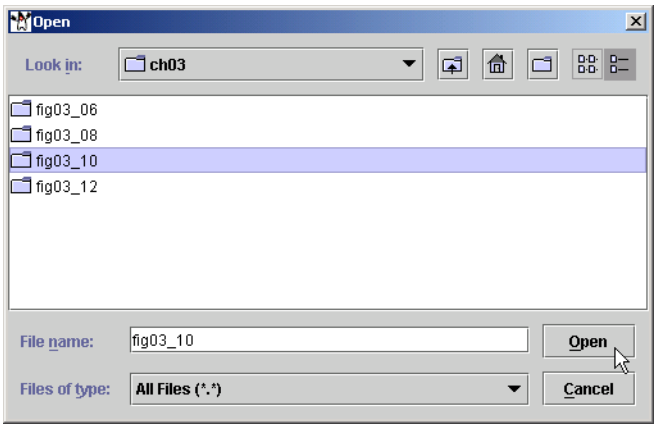

Fig. 3.16 Selecting the directory containing HTML files to convert.

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The **Java Plug-in HTML Converter** window after selecting the directory containing files to convert.

The **Template File** drop-down list allows you to choose the browsers in which to use the plug-in to execute applets.

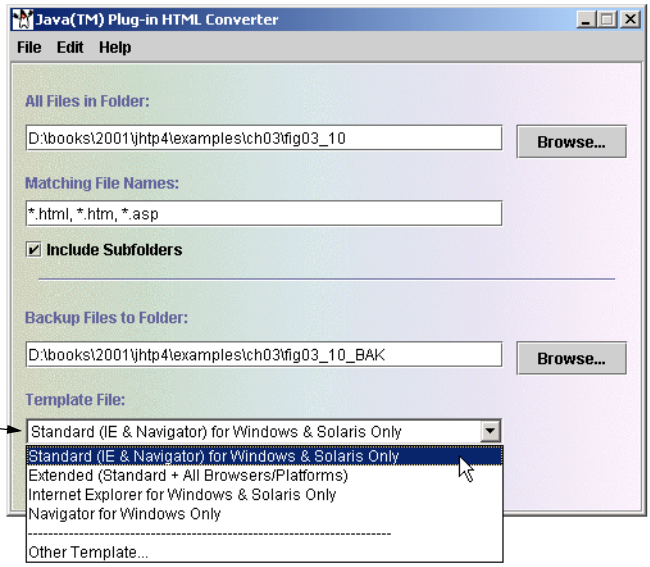

Fig. 3.17 Selecting the template used to convert the HTML files.

The confirmation dialog showing that the converter found and converted one applet in an HTML file in the specified directory.

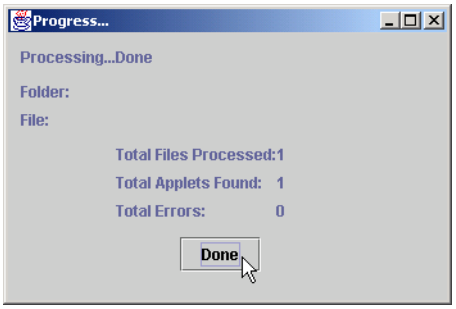

Fig. 3.18 Confirmation dialog after conversion completes.

3.7 Java Applet Internet and World Wide Web Resources

If you have access to the Internet and the World Wide Web, there are a large number of Java applet resources available to you. The best place to start is at the source—the Sun Microsystems, Inc. Java Web site **`java.sun.com`**. In the upper-left corner of the Web page is an ***Applets*** *hyperlink* that takes you to the Web page

`java.sun.com/applets`

This page contains a variety of Java applet resources, including free applets you can use on your own World Wide Web site, the demonstration applets from the J2SDK and a variety of other applets (many of which can be downloaded and used on your own computer).

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There is also a section entitled "Applets at Work" where you can read about uses of applets in industry.

On the Sun Microsystems Java Web site, visit the *Java Developer Connection*

```
developer.java.sun.com/developer
```

This free site includes technical support, discussion forums, on-line training courses, technical articles, resources, announcements of new Java features, early access to new Java technologies, and links to other important Java Web sites. Even though the site is free, you must register to use it.

Another useful Web site is *JARS*—originally called the *Java Applet Rating Service*. The JARS site

```
www.jars.com
```

calls itself the "#1 Java Review Service." This site originally was a large Java repository for applets. Its benefit was that it rated every applet registered at the site as top 1%, top 5% and top 25%, so you could view the best applets on the Web. Early in the development of the Java language, having your applet rated here was a great way to demonstrate your Java programming abilities. JARS is now all-around resource for Java programmers.

The resources listed in this section provide hyperlinks to many other Java-related Web sites. If you have Internet access, spend some time browsing these sites, executing applets and reading the source code for the applets when it is available. This will help you rapidly expand your Java expertise. Appendix B contains many other Web-based Java resources.

3.8 (Optional Case Study) Thinking About Objects: Identifying the Classes in a Problem Statement

Now we begin the substantial task of designing the elevator simulator model, which represents the workings of the elevator system. We will design the user interaction and display of this model in Section 12.16 and Section 22.9, respectively.

Identifying the Classes in a System

The first step of our OOD process is to identify the classes in our model. We will eventually describe these classes in a formal way and implement them in Java. First, we review the problem statement and locate all the *nouns*; it is likely that these include most of the classes (or instances of classes) necessary to implement the elevator simulation. Figure 3.19 is a list of these nouns (and noun phrases) in the order of their appearance.

Nouns (and noun phrases) in the problem statement

company	elevator system	graphical user interface (GUI)
office building	elevator shaft	elevator car
elevator	display	person
software-simulator application	model	floor (first floor; second floor)

Fig. 3.19 Nouns (and noun phrases) in problem statement (part 1 of 2).

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Nouns (and noun phrases) in the problem statement		
passenger	bell inside the elevator	**First Floor** GUI button
floor door	light on that floor	**Second Floor** GUI button
user of our application	energy	audio
floor button	capacity	elevator music
elevator button		

Fig. 3.19 Nouns (and noun phrases) in problem statement (part 2 of 2).

We choose only the nouns that perform important duties in our model. For this reason we omit several nouns (the next paragraph explains why each is omitted):

- company
- office building
- display
- graphical user interface (GUI)
- user of our application
- energy
- capacity
- **First Floor** and **Second Floor** GUI buttons
- audio
- elevator music

We do not need to model "company," as a class, because the company is not part of the simulation; the company simply wants us to model the elevator. We do not model the office building, or the actual place the elevator is situated, because the building does not affect *how* our elevator simulation operates. The phrases "display," "audio" and "elevator music" pertain to the presentation of the model, but do not pertain to the model itself. We use these phrases when we construct the presentation in Section 22.9 and Appendix I. The phrases "graphical user interface," "user of our application" and "**First Floor** and **Second Floor** GUI buttons" pertain to how the user controls the model, but they do not represent the model. We use these phrases when we construct the user interface in Section 12.16. "Capacity" is a property of the elevator and of the floor—not a separate entity itself. Lastly, although we'll be saving energy with the policy of not moving the elevator until requested, we do not model "energy."

We determine the classes for our system by grouping the remaining nouns into categories. We discard "elevator system" for the time being—we focus on designing only the system's model and disregard how this model relates to the system as a whole. (We discuss the system as a whole in Section 13.17.) Using this logic, we discard "simulation," because the simulation *is* the system in our case study. Lastly, we combine "elevator" and "elevator car" into "elevator," because the problem statement uses the two words interchangeably. Each remaining noun from Fig. 3.19 refers to one or more of the following categories:

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- model
- elevator shaft
- elevator
- person
- floor (first floor, second floor)
- elevator door
- floor door
- elevator button
- floor button
- bell
- light

These categories are likely to be classes we will need to implement our system. Notice that we create one category for the buttons on the floors and one category for the button on the elevator. The two types of buttons perform different duties in our simulation—the buttons on the floors summon the elevator, and the button in the elevator informs the elevator to move to the other floor.

We can now model the classes in our system based on the categories we created. By convention, we capitalize class names in the design process (as we will do when we write the actual Java program that implements our design). If the name of a class contains more than one word, we run the words together and capitalize each word (e.g., **`MultipleWordName`**). Using this convention, we create classes **`ElevatorModel`**,[3] **`ElevatorShaft`**, **`Elevator`**, **`Person`**, **`Floor`**, **`ElevatorDoor`**, **`FloorDoor`**, **`ElevatorButton`**, **`FloorButton`**, **`Bell`** and **`Light`**. We construct our system using all of these classes as building blocks. Before we begin building the system, however, we must gain a better understanding of how the classes relate to one another.

Class Diagrams

The UML enables us to model, via the *class diagram*, the classes in the elevator system and their interrelationships. Class diagrams model the structure of the system by providing the classes, or "building blocks," of the system. Figure 3.20 represents class **`Elevator`** using the UML. In a class diagram, each class is modeled as a rectangle. We then divide this rectangle into three parts. The top part contains the name of the class. The middle part contains the class' *attributes*. (We discuss attributes in "Thinking About Objects" Section 4.14 and Section 5.11.) The bottom part of the rectangle contains the class' *operations* (discussed in "Thinking About Objects," Section 6.17).

3. When we refer to the "elevator model," we imply all classes composing the model describing the operation of our elevator system—in other words, in our simulation, several classes comprise the model. We will see in Section 13.17 that our system requires a single class to represent the model—we create class **`ElevatorModel`** to act as the "representative" for the model, because, as we will see in Fig. 3.23, **`ElevatorModel`** is the class that aggregates all other classes comprising the model.

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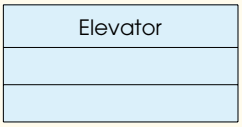

Fig. 3.20 Representing a class in the UML.

Classes relate to one another via *associations*. Figure 3.21 shows how our classes **ElevatorShaft**, **Elevator** and **FloorButton** relate to one another. Notice that the rectangles in this diagram are not subdivided into three sections. The UML allows the suppression of class attributes and operations in this manner to create more readable diagrams. Such a diagram is said to be an *elided diagram*, (i.e., some information, such as the contents for the second and bottom compartments), is not modeled. We place information in these compartments in Section 4.14 and Section 6.17, respectively.

In this class diagram, a solid line that connects classes represents an *association*. An association is a relationship between classes. The numbers near the lines express *multiplicity* values. Multiplicity values indicate how many objects of a class participate in the association. From the diagram, we see that two objects of class **FloorButton** participate in the association with one object of class **ElevatorShaft**, because the two **FloorButton**s are located on the **ElevatorShaft**. Therefore, class **FloorButton** has a *two-to-one* relationship with class **ElevatorShaft**; we can also say that class **ElevatorShaft** has a *one-to-two* relationship with class **FloorButton**. We also see that class **ElevatorShaft** has a *one-to-one* relationship with class **Elevator** and vice versa. Using the UML, we can model many types of multiplicity. Figure 3.22 shows the multiplicity types and how to represent them.

An association can be named. For example, the word **Requests** above the line connecting classes **FloorButton** and **Elevator** indicates the name of that association—the arrow shows the direction of the association. This part of the diagram reads "one object of class **FloorButton** requests one object of class **Elevator**." Note that associations are directional with the direction indicated by the arrowhead next to the association name—so it would be improper, for example, to read the preceding association as "one object of class **Elevator** requests one object of class **FloorButton**." In addition, the word **Resets** indicates that "one object of class **ElevatorShaft** resets two objects of class **FloorButton**." Lastly, the phrase **Signals arrival** indicates that "one object of class **Elevator** signals the **Elevator** object's arrival to one object of class **ElevatorShaft**."

The diamond attached to the association lines of class **ElevatorShaft** indicates that class **ElevatorShaft** has an *aggregation* relationship with classes **FloorButton** and **Elevator**. Aggregation implies a whole/part relationship. The class that has the aggregation symbol (the hollow diamond) on its end of an association line is the whole (in this case, **ElevatorShaft**), and the class on the other end of the association line is the part (in this case, classes **FloorButton** and **Elevator**). In this example, the elevator shaft "has an" elevator and two floor buttons. The "has a/has an" relationship defines aggregation (we will see in Section 9.23 that the "is a/is an" relationship defines inheritance).

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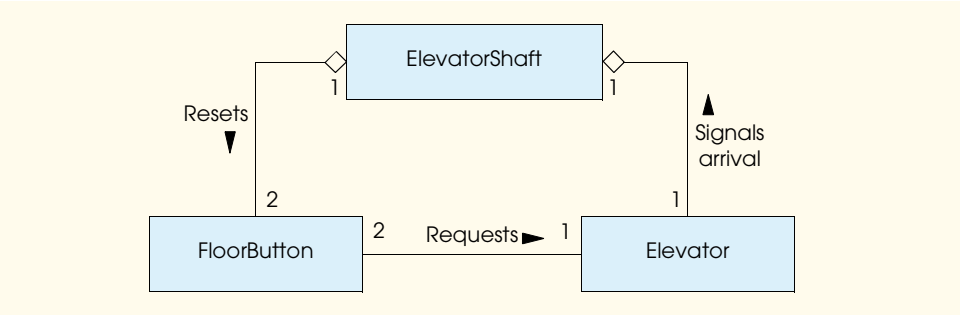

Fig. 3.21 Class diagram showing associations among classes.

Symbol	Meaning
0	None.
1	One.
m	An integer value.
0..1	Zero or one.
m, n	*m* or *n*
m..n	At least *m*, but not more than *n*.
*	Zero or more.
0..*	Zero or more
1..*	One or more

Fig. 3.22 Multiplicity types.

Figure 3.23 shows the complete class diagram for the elevator model. We model all classes that we created, as well as the associations between these classes. [*Note*: In Chapter 9, we expand our class diagram by using the object-oriented concept of *inheritance*.]

Class **`ElevatorModel`** is represented near the top of the diagram and aggregates one object of class **`ElevatorShaft`** and two objects of class **`Floor`**. The **`ElevatorShaft`** class is an aggregation of one object of class **`Elevator`** and two objects each of classes **`Light`**, **`FloorDoor`** and **`FloorButton`**. (Notice the two-to-one relationships between each of these classes and **`ElevatorShaft`**.) Class **`Elevator`** is an aggregation of classes **`ElevatorDoor`**, **`ElevatorButton`** and **`Bell`**. Class **`Person`** has associations with both **`FloorButton`** and **`ElevatorButton`** (and other classes, as we will soon see). The *association name* **`Presses`** and the *name-direction* arrowheads indicate that the object of class **`Person`** presses these buttons. The object of class **`Person`** also rides the object of class **`Elevator`** and walks across the object of class **`Floor`**. The name **`Requests`** indicates that an object of class **`FloorButton`** requests the object of class **`Elevator`**. The name **`Signals to move`** indicates that the object of class **`ElevatorButton`** signals the object of class **`Elevator`** to move to the other floor. The diagram indicates many other associations, as well.

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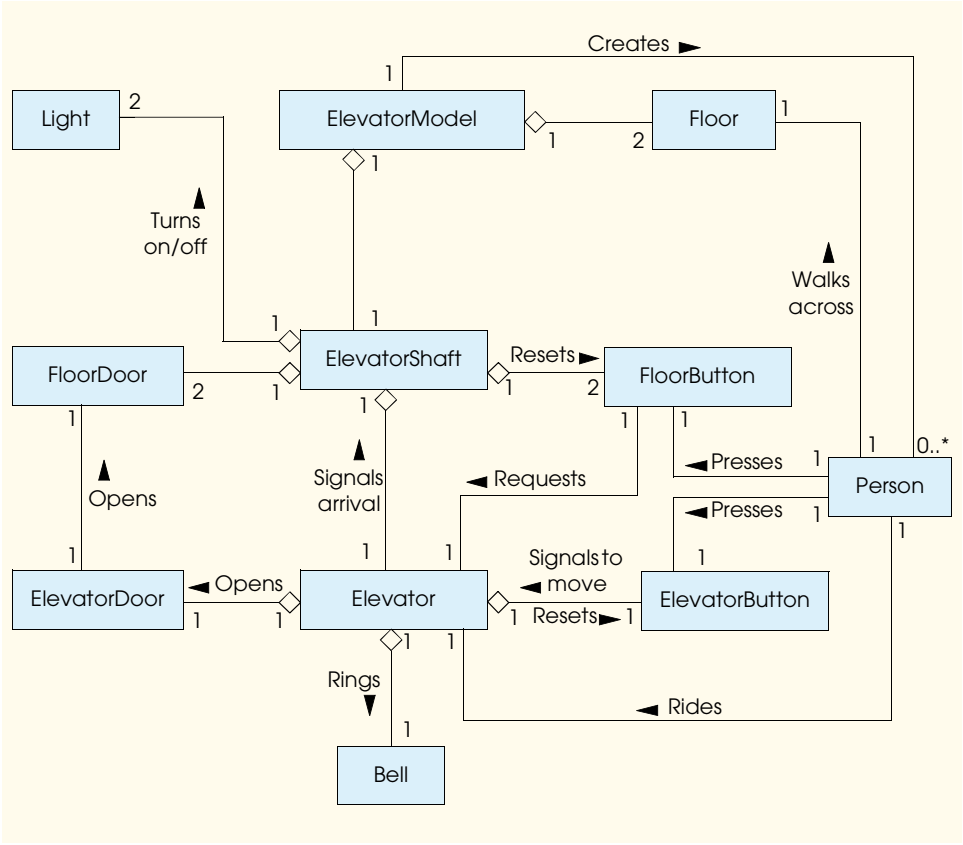

Fig. 3.23 Class diagram for the elevator model.

Object Diagrams

The UML also defines *object diagrams*, which are similar to class diagrams in that both diagrams model the structure of the system. However, object diagrams model objects (instances of classes) *at a specific time* in program execution. Object diagrams present a snapshot of the structure while the system is running, providing information about which objects are participating in the system at a definite point in time. Object diagrams represent relationships between objects as solid lines—these relationship are called *links*.

Figure 3.24 models a snapshot of the system when no people are in the building (i.e., no objects of class **`Person`** exist in the system at this point in time). Objects usually are written in the form **`objectName : ClassName`**—**`objectName`** refers to the name of the object, and **`ClassName`** refers to the class to which that object belongs. All names in an object diagram are underlined. The UML permits us to omit the object names for objects in the diagram where there exists only one object of that class (e.g., one object of class **`Bell`** at the bottom of the diagram). In large systems, object diagrams can contain many objects. This can result in cluttered, hard-to-read diagrams. If the name of a particular object is unknown, or if it is not necessary to include the name (i.e., we care only about the object type), we can disregard the object name and display only the colon and the class name.

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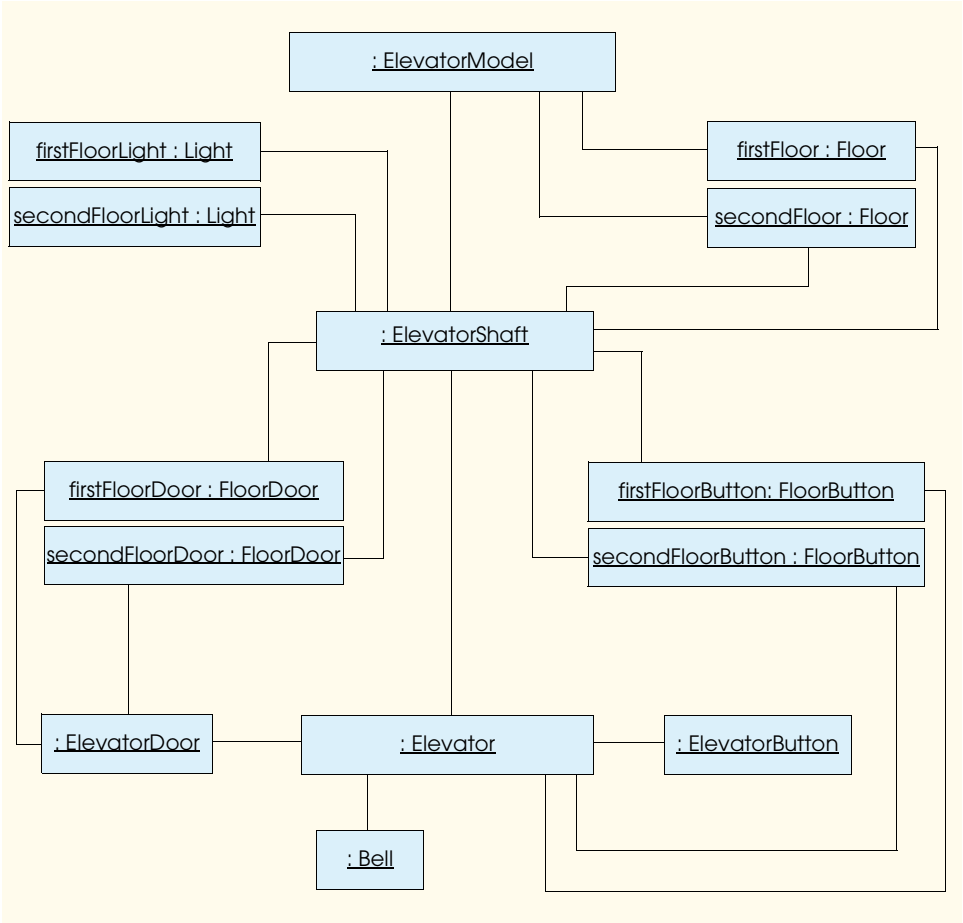

Fig. 3.24 Object diagram of an empty building in our elevator model.

Now we have identified the classes for our system (although we may discover others in later phases of the design process). In "Thinking About Objects," Section 4.14, we determine the attributes for each of these classes, and in "Thinking About Objects," Section 5.11, we use these attributes to examine how the system changes over time and to introduce its behavioral aspects. As we expand our knowledge, we will discover new information that will enable us to describe our classes more completely. Because the real world is inherently object oriented, it will be quite natural for you to pursue this project, even though you might have just begun your study of object orientation.

Questions

1. Why might it be more complicated to implement a three-story (or taller) building?
2. It is common for large buildings to have many elevators. We will see in Chapter 9 that once we have created one elevator object, it is easy to create as many as we like. What problems or opportunities do you foresee in having several elevators,

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each of which may pick up and discharge passengers at every floor in a large building?

3. For simplicity, we have given our elevator and each floor a capacity of one passenger. What problems and opportunities do you foresee in being able to increase these capacities?

SUMMARY

- Applets are Java programs that can be embedded in Hypertext Markup Language (HTML) documents (i.e., Web pages). When a browser loads a Web page containing an applet, the applet downloads into the Web browser and begins execution.
- In the **`appletviewer`**, you can execute an applet again by clicking the appletviewer's **Applet** menu and selecting the **Reload** option from the menu. To terminate an applet, click the **`appletviewer`**'s **Applet** menu and select the **`Quit`** option.
- Class **`Graphics`** is located in package **`java.awt`**. Import the **`Graphics`** class so the program can draw graphics.
- Class **`JApplet`** is located in package **`javax.swing`**. When you create an applet in Java, you must import the **`JApplet`** class.
- Java uses inheritance to create new classes from existing class definitions. Keyword **`extends`** followed by a class name indicates the class from which a new class inherits.
- In the inheritance relationship, the class following **`extends`** is called the superclass or base class and the new class is called the subclass or derived class. Using inheritance results in a new class definition that has the attributes (data) and behaviors (methods) of the superclass as well as the new features added in the subclass definition.
- A benefit of extending class **`JApplet`** is that someone else already has defined "what it means to be an applet." The **`appletviewer`** and World Wide Web browsers that support applets expect every Java applet to have certain capabilities (attributes and behaviors), and class **`JApplet`** already provides those capabilities.
- Classes are used as "templates" or "blueprints" to instantiate (or create) objects in memory for use in a program. An object (or instance) is a region in the computer's memory in which information is stored for use by the program. The term object normally implies that attributes (data) and behaviors (methods) are associated with the object and that those behaviors perform operations on the attributes of the object.
- Method **`paint`** is one of three methods (behaviors) that an applet container calls when any applet begins execution. These three methods are **`init`**, **`start`** and **`paint`**, and they are guaranteed to be called in that order.
- The parameter list is where methods receive data required to complete their tasks. Normally, this data is passed by the programmer to the method through a method call (also known as invoking a method). In the case of method **`paint`**, the applet container calls the method and passes the **`Graphics`** argument.
- Method **`drawString`** of class **`Graphics`** draws a string at the specified location on the applet. The first argument to **`drawString`** is the **`String`** to draw. The last two arguments in the list are the coordinates (or position) at which the string should be drawn. Coordinates are measured from the upper-left (0, 0) coordinate of the applet in pixels.
- You must create an HTML (Hypertext Markup Language) file to load an applet into an applet container, so the applet container can execute the applet.

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- Many HTML codes (referred to as tags) come in pairs. HTML tags begin with a left angle bracket **<** and end with a right angle bracket **>**.
- Normally, the applet and its corresponding HTML file are stored in the same directory on disk.
- The first component of the **<applet>** tag indicates the file containing the compiled applet class. The second and third components of the **<applet>** tag indicate the **width** and the **height** of the applet in pixels. Generally, each applet should be less than 800 pixels wide and 600 pixels tall.
- The **appletviewer** only understands the **<applet>** and **</applet>** HTML tags, so it is sometimes referred to as the "minimal browser." It ignores all other HTML tags.
- Method **drawLine** of class **Graphics** draws lines. The method requires four arguments representing the two end points of the line on the applet—the x-coordinate and y-coordinate of the first end point in the line and the x-coordinate and y-coordinate of the second end point in the line. All coordinate values are specified with respect to the upper-left corner (0, 0) coordinate of the applet.
- Primitive data type **double** stores double-precision floating-point numbers. Primitive data type **float** stores single-precision floating-point numbers. A **double** requires more memory to store a floating-point value, but stores it with approximately twice the precision of a **float** (15 significant digits for **double** vs. seven significant digits for **float**).
- The **import** statements are not required if you always use the complete name of a class, including the full package name and class name (e.g., **java.awt.Graphics**).
- The asterisk (*****) notation after a package name in an **import** indicates that all classes in the package should be available to the compiler so the compiler can ensure that the classes are used correctly. This allows programmers to use the shorthand name (the class name by itself) of any class from the package in the program.
- Every instance (object) of a class contains one copy of each of that class's instance variables. Instance variables are declared in the body of a class definition, but not in the body of any method of that class definition. An important benefit of instance variables is that their identifiers can be used in all methods of the class.
- Variables defined in the body of a method are known as local variables and can be used only in the body of the method in which they are defined.
- Instance variables are always assigned a default value, and local variables are not.
- Method **init** normally initializes the applet's instance variables (if they need to be initialized to a value other than their default value) and performs any tasks that should occur only once when the applet begins execution
- There are actually two types of variables in Java—primitive data type variables and references.
- References refer to objects in a program. References actually contain the location in the computer's memory of an object. A reference is used to send messages to (i.e., call methods on) the object in memory. As part of the message (method call), we provide the data (arguments) that the method requires to do its task.
- A variable is similar to an object. The primary difference between a variable and an object is that an object is defined by a class definition that can contain both data (instance variables) and methods, whereas a variable is defined by a primitive (or built-in) data type (one of **char**, **byte**, **short**, **int**, **long**, **float**, **double** or **boolean**) that can contain only data.
- A variable can store exactly one value at a time, whereas one object can contain many individual data members.
- If the data type used to declare a variable is a class name, the identifier is a reference to an object and that reference can be used to send messages to (call methods on) that object. If the data type used to declare a variable is one of the primitive data types, the identifier is a variable that can be used to store in memory or retrieve from memory a single value of the declared primitive type.

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- Method **`Double.parseDouble`** (a **`static`** method of class **`Double`**) converts its **`String`** argument to a **`double`** floating-point value. Class **`Double`** is part of the package **`java.lang`**.
- Method **`drawRect`** draws a rectangle based on its four arguments. The first two integer values represent the upper-left x-coordinate and upper-left y-coordinate where the **`Graphics`** object begins drawing the rectangle. The third and fourth arguments are non-negative integers that represent the width of the rectangle in pixels and the height of the rectangle in pixels, respectively.
- To use the features of Java 2 in an applet, Sun provides the Java Plug-in to bypass a browser's Java support and use a complete version of the Java 2 Runtime Environment (J2RE) that is installed on the user's local computer.
- To specify that an applet should use the Java Plug-in rather than the browser's Java support, use the HTML Converter to convert the applet's **`<applet>`** and **`</applet>`** tags in the HTML file to indicate that the applet container should use the Plug-in to execute the applet. Sun provides the Java Plug-in 1.3 HTML Converter to perform the conversion for you.

TERMINOLOGY

applet
applet container
`<applet>` tag
Applet menu
`appletviewer`
`boolean` primitive type
browser
built-in data type
`byte` primitive type
`char` primitive type
command-line argument
coordinate
create an object
derived class
`double` primitive data type
`Double.parseDouble` method
double-precision floating-point number
`drawLine` method of class **`Graphics`**
`drawRect` method of class **`Graphics`**
`drawString` method of class **`Graphics`**
`extends` keyword
`float` primitive type
floating-point number
`Graphics` class
`height` of an applet
HTML Converter
HTML tag
Hypertext Markup Language (HTML)
import statement
information hiding
`init` method of class **`JApplet`**
instance variable
instantiate an object
`int` primitive type
interface
invoke a method
`JApplet` class
`java.awt` package
Java Plug-in
Java 2 Runtime Environment (J2RE)
`javax.swing` package
local variable
logic error
`long` primitive type
message
method call
Microsoft Internet Explorer
Netscape Communicator
object
`paint` method of class **`JApplet`**
parameter list
pixel (picture element)
primitive data type
Quit menu item
references
Reload menu item
`short` primitive type
single-precision floating-point number
source code
`start` method of class **`JApplet`**
subclass
superclass
text file
`width` of an applet
World Wide Web

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SELF-REVIEW EXERCISES

3.1 Fill in the blanks in each of the following.

a) Class _____ provides methods for drawing.
b) Java applets begin execution with a series of three method calls: _____, _____ and _____.
c) Methods _____ and _____ display lines and rectangles.
d) Keyword _____ indicates that a new class is a subclass of an existing class.
e) Every Java applet should extend either class _____ or class _____.
f) Java's eight primitive data types are _____, _____, _____, _____, _____, _____, _____ and _____.

3.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) To draw a rectangle, method **`drawRect`** requires four arguments that specify two points on the applet.
b) Method **`drawLine`** requires four arguments that specify two points on the applet to draw a line.
c) Type **`Double`** is a primitive data type.
d) Data type **`int`** is used to declare a floating-point number.
e) Method **`Double.parseDouble`** converts a **`String`** to a primitive **`double`** value.

3.3 Write Java statements to accomplish each of the following:

a) Display a dialog asking the user to enter a floating-point number.
b) Convert a **`String`** to a floating-point number and store the converted value in **`double`** variable **`age`**. Assume that the **`String`** is stored in **`stringValue`**.
c) Draw the message **`"This is a Java program"`** on one line on an applet (assume you are defining this statement in the applet's **`paint`** method) at position *(10, 10)*.
d) Draw the message **`"This is a Java program"`** on two lines on an applet (assume these statements are defined in applet method **`paint`**) starting at position *(10, 10)* and where the first line ends with **`Java`**. Make the two lines start at the same *x* coordinate.

ANSWERS TO SELF-REVIEW EXERCISES

3.1 a) **`Graphics`**. b) **`init`**, **`start`**, **`paint`**. c) **`drawLine`**, **`drawRect`**. d) **`extends`**. e) **`JApplet`**, **`Applet`**. f) **`byte`**, **`short`**, **`int`**, **`long`**, **`float`**, **`double`**, **`char`** and **`boolean`**.

3.2 a) False. Method **`drawRect`** requires four arguments—two that specify the upper-left corner of the rectangle and two that specify the width and height of the rectangle. b) True. c) False. Type **`Double`** is a class in the **`java.lang`** package. Remember that names that start with a capital letter are normally class names. d) False. Data type **`double`** or data type **`float`** can be used to declare a floating-point number. Data type **`int`** is used to declare integers. e) True.

3.3 a)

```
stringValue = JOptionPane.showInputDialog(
   "Enter a floating-point number" );
```

b)

```
age = Double.parseDouble( stringValue );
```

c)

```
g.drawString( "This is a Java program", 10, 10 );
```

d)

```
g.drawString( "This is a Java", 10, 10 );
g.drawString( "program", 10, 25 );
```

EXERCISES

3.4 Fill in the blanks in each of the following:

a) Data type _____ declares a single-precision floating-point variable.

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b) If class **Double** provides method **parseDouble** to convert a **String** to a **double** and class **Integer** provides method **parseInt** to convert a **String** to an **int**, then class **Float** probably provides method __________ to convert a **String** to a **float**.
c) Data type __________ declares a double-precision floating-point variable.
d) The __________ or a browser can be used to execute a Java applet.
e) To load an applet into a browser you must first define a(n) __________ file.
f) The __________ and __________ HTML tags specify that an applet should be loaded into an applet container and executed.

3.5 State whether each of the following is *true* or *false*. If *false*, explain why.
a) All browsers support Java 2.
b) When using an **import** of the form **javax.swing.***, all classes in the package are imported.
c) You do not need import statements if the full package name and class name are specified each time you refer to a class in a program.

3.6 Write an applet that asks the user to enter two floating-point numbers, obtains the two numbers from the user and draws the sum, product (multiplication), difference and quotient (division) of the two numbers. Use the techniques shown in Fig. 3.12.

3.7 Write an applet that asks the user to enter two floating-point numbers, obtains the numbers from the user and displays the larger number followed by the words "**is larger**" as a string on the applet. If the numbers are equal, print the message "**These numbers are equal**." Use the techniques shown in Fig. 3.12.

3.8 Write an applet that inputs three floating-point numbers from the user and displays the sum, average, product, smallest and largest of these numbers as strings on the applet. Use the techniques shown in Fig. 3.12.

3.9 Write an applet that inputs from the user the radius of a circle as a floating-point number and draws the circle's diameter, circumference and area. Use the value 3.14159 for π. Use the techniques shown in Fig. 3.12. [Note: You may also use the predefined constant **Math.PI** for the value of π. This constant is more precise than the value 3.14159. Class **Math** is defined in the **java.lang** package, so you do not need to **import** it.] Use the following formulas (*r* is the radius):

$$diameter = 2r$$
$$circumference = 2\pi r$$
$$area = \pi r^2$$

3.10 Write an applet that draws a box, an oval, an arrow and a diamond using asterisks (*****) as follows:

```
*********          ***              *              *
*       *        *     *           ***            * *
*       *       *       *         *****          *   *
*       *       *       *           *           *     *
*       *       *       *           *          *       *
*       *       *       *           *           *     *
*       *       *       *           *            *   *
*       *        *     *            *             * *
*********          ***              *              *
```

3.11 Write an applet that reads five integers and determines and prints the largest and smallest integers in the group. Use only the programming techniques you learned in this chapter and Chapter 2. Draw the results on the applet.

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3.12 Write an applet that reads in two floating-point numbers and determines and prints if the first is a multiple of the second. (*Hint*: Use the modulus operator.) Use only the programming techniques you learned in this chapter and Chapter 2. Draw the results on the applet.

3.13 Write an applet that draws a checkerboard pattern as follows:

```
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
```

3.14 Write an applet that draws a variety of rectangles of different sizes and locations.

3.15 Write an applet that allows the user to input the four arguments required by method **drawRect**, then draws a rectangle using the four input values.

3.16 The **Graphics** class contains a **drawOval** method that takes the same four arguments as method **drawRect**. However, the arguments for method **drawOval** specify the "bounding box" for the oval. The sides of the bounding box are the boundaries of the oval. Write a Java applet that draws an oval and a rectangle with the same four arguments. You will see that the oval touches the rectangle at the center of each side.

3.17 Modify the solution to Exercise 3.16 to output a variety of ovals of different shapes and sizes.

3.18 Write an applet that allows the user to input the four arguments required by method **drawOval**, then draws an oval using the four input values.

3.19 What does the following code print?

```
g.drawString( "*", 25, 25 );
g.drawString( "***", 25, 55 );
g.drawString( "******", 25, 85 );
g.drawString( "*****", 25, 70 );
g.drawString( "**", 25, 40 );
```

3.20 Using only programming techniques from Chapter 2 and Chapter 3, write an applet that calculates the squares and cubes of the numbers from 0 to 10 and draws the resulting values in table format as follows:

```
number  square  cube
0       0       0
1       1       1
2       4       8
3       9       27
4       16      64
5       25      125
6       36      216
7       49      343
8       64      512
9       81      729
10      100     1000
```

[*Note*: This program does not require any input from the user.]

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4

Control Structures: Part 1

Objectives

- To understand basic problem-solving techniques.
- To be able to develop algorithms through the process of top-down, stepwise refinement.
- To be able to use the **`if`** and **`if/else`** selection structures to choose among alternative actions.
- To be able to use the **`while`** repetition structure to execute statements in a program repeatedly.
- To understand counter-controlled repetition and sentinel-controlled repetition.
- To be able to use the increment, decrement and assignment operators.

Let's all move one place on.
Lewis Carroll

The wheel is come full circle.
William Shakespeare, *King Lear*

How many apples fell on Newton's head before he took the hint!
Robert Frost, comment

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Outline

4.1 Introduction
4.2 Algorithms
4.3 Pseudocode
4.4 Control Structures
4.5 The `if` Selection Structure
4.6 The `if/else` Selection Structure
4.7 The `while` Repetition Structure
4.8 Formulating Algorithms: Case Study 1 (Counter-Controlled Repetition)
4.9 Formulating Algorithms with Top-Down, Stepwise Refinement: Case Study 2 (Sentinel-Controlled Repetition)
4.10 Formulating Algorithms with Top-Down, Stepwise Refinement: Case Study 3 (Nested Control Structures)
4.11 Assignment Operators
4.12 Increment and Decrement Operators
4.13 Primitive Data Types
4.14 (Optional Case Study) Thinking About Objects: Identifying Class Attributes

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

4.1 Introduction

Before writing a program to solve a problem, it is essential to have a thorough understanding of the problem and a carefully planned approach to solving the problem. When writing a program, it is equally essential to understand the types of building blocks that are available and to employ proven program construction principles. In this chapter and in Chapter 5, we discuss these issues in our presentation of the theory and principles of structured programming. The techniques you learn here are applicable to most high-level languages, including Java. When we study object-based programming in more depth in Chapter 8, we will see that control structures are helpful in building and manipulating objects.

4.2 Algorithms

Any computing problem can be solved by executing a series of actions in a specific order. A *procedure* for solving a problem in terms of

1. the *actions* to be executed and
2. the *order* in which the actions are to be executed

is called an *algorithm*. The following example demonstrates that correctly specifying the order in which the actions are to be executed is important.

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Consider the "rise-and-shine algorithm" followed by one junior executive for getting out of bed and going to work: (1) Get out of bed, (2) take off pajamas, (3) take a shower, (4) get dressed, (5) eat breakfast, (6) carpool to work.

This routine gets the executive to work well prepared to make critical decisions. Suppose, however, that the same steps are performed in a slightly different order: (1) Get out of bed, (2) take off pajamas, (3) get dressed, (4) take a shower, (5) eat breakfast, (6) carpool to work.

In this case, our junior executive shows up for work soaking wet. Specifying the order in which statements are to be executed in a computer program is called *program control*. In this chapter and Chapter 5, we investigate the program control capabilities of Java.

4.3 Pseudocode

Pseudocode is an artificial and informal language that helps programmers develop algorithms. The pseudocode we present here is particularly useful for developing algorithms that will be converted to structured portions of Java programs. Pseudocode is similar to everyday English; it is convenient and user friendly, although it is not an actual computer programming language.

Pseudocode programs are not actually executed on computers. Rather, they help the programmer "think out" a program before attempting to write it in a programming language, such as Java. In this chapter, we give several examples of pseudocode programs.

Software Engineering Observation 4.1

Pseudocode is often used to "think out" a program during the program design process. Then the pseudocode program is converted to Java.

The style of pseudocode we present consists purely of characters, so programmers may conveniently type pseudocode programs using an editor program. The computer can produce a freshly printed copy of a pseudocode program on demand. A carefully prepared pseudocode program may be converted easily to a corresponding Java program. This conversion is done in many cases simply by replacing pseudocode statements with their Java equivalents.

Pseudocode normally describes only executable statements—the actions that are performed when the program is converted from pseudocode to Java and is run. Declarations are not executable statements. For example, the declaration

```
int i;
```

tells the compiler the type of variable `i` and instructs the compiler to reserve space in memory for the variable. This declaration does not cause any action—such as input, output or a calculation—to occur when the program is executed. Some programmers choose to list variables and mention the purpose of each at the beginning of a pseudocode program.

4.4 Control Structures

Normally, statements in a program are executed one after the other in the order in which they are written. This process is called *sequential execution*. Various Java statements we will soon discuss enable the programmer to specify that the next statement to be executed may be other than the next one in sequence. This is called *transfer of control*.

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During the 1960s, it became clear that the indiscriminate use of transfers of control was the root of much difficulty experienced by software development groups. The finger of blame was pointed at the ***goto*** *statement* (used in several programming languages, including C and Basic), which allows the programmer to specify a transfer of control to one of a very wide range of possible destinations in a program. The notion of so-called *structured programming* became almost synonymous with "**goto** elimination." Java does not have a **goto** statement; however, **goto** is a reserved word and should not be used in a Java program.

The research of Bohm and Jacopini[1] had demonstrated that programs could be written without any **goto** statements. The challenge of the era for programmers was to shift their styles to "**goto**-less programming." It was not until the 1970s that programmers started taking structured programming seriously. The results have been impressive, as software development groups have reported reduced development times, more frequent on-time delivery of systems and more frequent within-budget completion of software projects. The key to these successes is that structured programs are clearer, easier to debug and modify and more likely to be bug free in the first place.

Bohm and Jacopini's work demonstrated that all programs could be written in terms of only three *control structures*—namely, the *sequence structure*, the *selection structure* and the *repetition structure*. The sequence structure is built into Java. Unless directed otherwise, the computer executes Java statements one after the other in the order in which they are written. The *flowchart* segment in Fig. 4.1 illustrates a typical sequence structure in which two calculations are performed in order.

A flowchart is a graphical representation of an algorithm or a portion of an algorithm. Flowcharts are drawn using certain special-purpose symbols, such as rectangles, diamonds, ovals and small circles; these symbols are connected by arrows called *flowlines*, which indicate the order in which the actions of the algorithm execute.

Like pseudocode, flowcharts are often useful for developing and representing algorithms, although pseudocode is strongly preferred by many programmers. Flowcharts show clearly how control structures operate; that is all we use them for in this text. The reader should carefully compare the pseudocode and flowchart representations of each control structure.

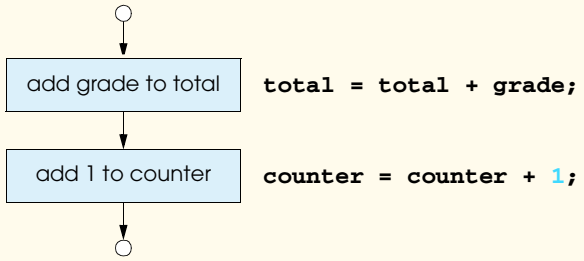

Fig. 4.1 Flowcharting Java's sequence structure.

1. Bohm, C., and G. Jacopini, "Flow Diagrams, Turing Machines, and Languages with Only Two Formation Rules," *Communications of the ACM*, Vol. 9, No. 5, May 1966, pp. 336–371.

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Consider the flowchart segment for the sequence structure in Fig. 4.1. We use the *rectangle symbol*, also called the *action symbol*, to indicate any type of action, including a calculation or an input/output operation. The flowlines in the figure indicate the order in which the actions are to be performed; first, **grade** is to be added to **total**, and then **1** is to be added to **counter**. Java allows us to have as many actions as we want in a sequence structure. As we will soon see, anywhere a single action may be placed, we may instead place several actions in sequence.

When drawing a flowchart that represents a *complete* algorithm, an *oval symbol* containing the word "Begin" is the first symbol used in the flowchart; an oval symbol containing the word "End" indicates where the algorithm ends. When drawing only a portion of an algorithm, as in Fig. 4.1, the oval symbols are omitted in favor of *small circle symbols*, also called *connector symbols*.

Perhaps the most important flowcharting symbol is the *diamond symbol*, also called the *decision symbol*, which indicates that a decision is to be made. We will discuss the diamond symbol in the next section.

Java provides three types of selection structures; we discuss each in this chapter and in Chapter 5. The **if** selection structure either performs (selects) an action, if a condition is true, or skips the action, if the condition is false. The **if/else** selection structure performs an action if a condition is true and performs a different action if the condition is false. The **switch** selection structure (Chapter 5) performs one of many different actions, depending on the value of an expression.

The **if** structure is called a *single-selection structure*, because it selects or ignores a single action (or, as we will soon see, a single group of actions). The **if/else** structure is called a *double-selection structure*, because it selects between two different actions (or groups of actions). The **switch** structure is called a *multiple-selection structure*, because it selects among many different actions (or groups of actions).

Java provides three types of repetition structures—namely, **while**, **do/while** and **for**. (**do/while** and **for** are covered in Chapter 5.) Each of the words **if**, **else**, **switch**, **while**, **do** and **for** are Java *keywords*. These words are reserved by the language to implement various features, such as Java's control structures. Keywords cannot be used as identifiers, such as for variable names. A complete list of Java keywords is shown in Fig. 4.2.

Java Keywords

abstract	**boolean**	**break**	**byte**	**case**
catch	**char**	**class**	**continue**	**default**
do	**double**	**else**	**extends**	**false**
final	**finally**	**float**	**for**	**if**
implements	**import**	**instanceof**	**int**	**interface**
long	**native**	**new**	**null**	**package**
private	**protected**	**public**	**return**	**short**

Fig. 4.2 Java keywords (part 1 of 2).

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Java Keywords

`static`	`super`	`switch`	`synchronized`	`this`
`throw`	`throws`	`transient`	`true`	`try`
`void`	`volatile`	`while`		

Keywords that are reserved, but not used, by Java

`const`	`goto`

Fig. 4.2 Java keywords (part 2 of 2).

Common Programming Error 4.1

Using a keyword as an identifier is a syntax error.

Well, that is all there is. Java has only seven control structures: the sequence structure, three types of selection structures and three types of repetition structures. Each program is formed by combining as many of each type of control structure as is appropriate for the algorithm the program implements. As with the sequence structure in Fig. 4.1, we will see that each control structure is flowcharted with two small circle symbols, one at the entry point to the control structure and one at the exit point.

Single-entry/single-exit control structures make it easy to build programs; the control structures are attached to one another by connecting the exit point of one control structure to the entry point of the next. This procedure is similar to the way in which a child stacks building blocks, so we call it *control-structure stacking*. We will learn that there is only one other way in which control structures may be connected: *control-structure nesting*. Thus, algorithms in Java programs are constructed from only seven different types of control structures, combined in only two ways.

4.5 The `if` Selection Structure

A selection structure is used to choose among alternative courses of action in a program. For example, suppose that the passing grade on an examination is 60 (out of 100). Then the pseudocode statement

```
If student's grade is greater than or equal to 60
    Print "Passed"
```

determines if the condition "student's grade is greater than or equal to 60" is true or false. If the condition is true, then "Passed" is printed, and the next pseudocode statement in order is "performed." (Remember that pseudocode is not a real programming language.) If the condition is false, the Print statement is ignored, and the next pseudocode statement in order is performed. Note that the second line of this selection structure is indented. Such indentation is optional, but it is highly recommended, because it emphasizes the inherent structure of structured programs. The Java compiler ignores white-space characters, like blanks, tabs and newlines, used for indentation and vertical spacing. Programmers insert these white-space characters to enhance program clarity.

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Good Programming Practice 4.1

Consistently applying reasonable indentation conventions throughout your programs improves program readability. We suggest a fixed-size tab of about ¼ inch or three spaces per indent.

The preceding pseudocode *if* statement may be written in Java as

```
if ( studentGrade >= 60 )
   System.out.println( "Passed" );
```

Notice that the Java code corresponds closely to the pseudocode. This attribute is a property of pseudocode that makes it a useful program development tool. The statement in the body of the **`if`** structure outputs the character string **`"Passed"`** in the command window.

The flowchart in Fig. 4.3 illustrates the single-selection **`if`** structure. This flowchart contains what is perhaps the most important flowcharting symbol—the *diamond symbol*, also called the *decision symbol*, which indicates that a decision is to be made. The decision symbol contains an expression, such as a condition, that can be either **`true`** or **`false`**. The decision symbol has two flowlines emerging from it. One indicates the direction to be taken when the expression in the symbol is true; the other indicates the direction to be taken when the expression is false. A decision can be made on any expression that evaluates to a value of Java's **`boolean`** type (i.e., any expression that evaluates to **`true`** or **`false`**).

Note that the **`if`** structure is a single-entry/single-exit structure. We will soon learn that the flowcharts for the remaining control structures also contain (besides small circle symbols and flowlines) only rectangle symbols, to indicate the actions to be performed, and diamond symbols, to indicate decisions to be made. This factor is indicative of the *action/decision model of programming* we have been emphasizing throughout this chapter.

We can envision seven bins, each containing only control structures of one of the seven types. These control structures are empty; nothing is written in the rectangles or in the diamonds. The programmer's task, then, is to assemble a program from as many of each type of control structure as the algorithm demands, combining the control structures in only two possible ways (stacking or nesting) and then filling in the actions and decisions in a manner appropriate for the algorithm. In this chapter we discuss the variety of ways in which actions and decisions may be written.

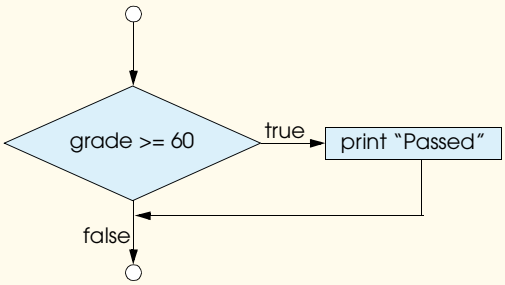

Fig. 4.3 Flowcharting the single-selection **`if`** structure.

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4.6 The `if/else` Selection Structure

The **`if`** selection structure performs an indicated action only when the given condition evaluates to **`true`**; otherwise, the action is skipped. The **`if/else`** selection structure allows the programmer to specify that a different action is to be performed when the condition is true rather than when the condition is false. For example, the pseudocode statement

```
If student's grade is greater than or equal to 60
    Print "Passed"
else
    Print "Failed"
```

prints *Passed* if the student's grade is greater than or equal to 60 and prints *Failed* if the student's grade is less than 60. In either case, after printing occurs, the next pseudocode statement in sequence is "performed." Note that the body of the *else* is also indented.

Good Programming Practice 4.2

*Indent both body statements of an **`if/else`** structure.*

The indentation convention you choose should be carefully applied throughout your programs. It is difficult to read programs that do not use uniform spacing conventions.

The preceding pseudocode *If/else* structure may be written in Java as

```
if ( studentGrade >= 60 )
   System.out.println( "Passed" );
else
   System.out.println( "Failed" );
```

The flowchart in Fig. 4.4 nicely illustrates the flow of control in an **`if/else`** structure. Once again, note that, besides small circles and arrows, the only symbols in the flowchart are rectangles (for actions) and a diamond (for a decision). We continue to emphasize this action/decision model of computing. Imagine again a deep bin containing as many empty double-selection structures as might be needed to build a Java algorithm. The programmer's job is to assemble the selection structures (by stacking and nesting) with other control structures required by the algorithm and to fill in the empty rectangles and empty diamonds with actions and decisions appropriate to the algorithm being implemented.

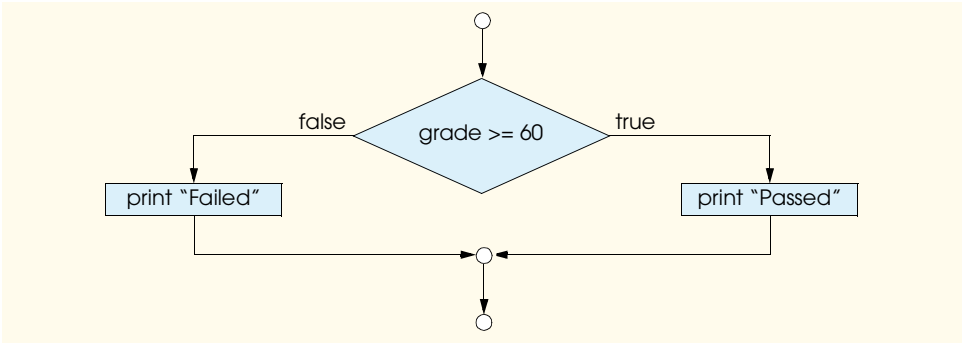

Fig. 4.4 Flowcharting the double-selection **`if/else`** structure.

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The *conditional operator* (**?:**) is related to the **if/else** structure. **?:** is Java's only *ternary operator*—it takes three operands. The operands together with **?:** form a *conditional expression*. The first operand is a **boolean** expression, the second is the value for the conditional expression if the condition evaluates to **true** and the third is the value for the conditional expression if the condition evaluates to **false**. For example, the statement

```
System.out.println( studentGrade >= 60 ? "Passed" : "Failed" );
```

contains a conditional expression that evaluates to the string **"Passed"** if the condition **studentGrade >= 60** is true and to the string **"Failed"** if the condition is false. Thus, this statement with the conditional operator performs essentially the same function as the **if/else** statement given previously. The precedence of the conditional operator is low, so the entire conditional expression is normally placed in parentheses. We will see that conditional operators can be used in some situations where **if/else** statements cannot.

Good Programming Practice 4.3

*In general, conditional expressions are more difficult to read than **if/else** structures. Such expressions should be used with discretion when they help improve a program's readability.*

*Nested **if/else** structures* test for multiple cases by placing **if/else** structures inside **if/else** structures. For example, the following pseudocode statement prints **A** for exam grades greater than or equal to 90, **B** for grades in the range 80 to 89, **C** for grades in the range 70 to 79, **D** for grades in the range 60 to 69 and **F** for all other grades:

```
If student's grade is greater than or equal to 90
    Print "A"
else
    If student's grade is greater than or equal to 80
        Print "B"
    else
        If student's grade is greater than or equal to 70
            Print "C"
        else
            If student's grade is greater than or equal to 60
                Print "D"
            else
                Print "F"
```

This pseudocode may be written in Java as

```
if ( studentGrade >= 90 )
   System.out.println( "A" );
else
   if ( studentGrade >= 80 )
      System.out.println( "B" );
   else
      if ( studentGrade >= 70 )
         System.out.println( "C" );
      else
         if ( studentGrade >= 60 )
            System.out.println( "D" );
         else
            System.out.println( "F" );
```

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If **studentGrade** is greater than or equal to 90, the first four conditions will be true, but only the **System.out.println** statement after the first test will be executed. After that particular **System.out.println** is executed, the **else** part of the "outer" **if/else** statement is skipped.

Good Programming Practice 4.4

If there are several levels of indentation, each level should be indented by the same additional amount of space.

Most Java programmers prefer to write the preceding **if** structure as

```
if ( grade >= 90 )
   System.out.println( "A" );
else if ( grade >= 80 )
   System.out.println( "B" );
else if ( grade >= 70 )
   System.out.println( "C" );
else if ( grade >= 60 )
   System.out.println( "D" );
else
   System.out.println( "F" );
```

Both forms are equivalent. The latter form is popular because it avoids the deep indentation of the code to the right. Such deep indentation often leaves little room on a line, forcing lines to be split and decreasing program readability.

It is important to note that the Java compiler always associates an **else** with the previous **if** unless told to do otherwise by the placement of braces (**{}**). This attribute is referred to as the *dangling-else problem*. For example,

```
if ( x > 5 )
   if ( y > 5 )
      System.out.println( "x and y are > 5" );
else
   System.out.println( "x is <= 5" );
```

appears to indicate that if **x** is greater than **5**, the **if** structure in its body determines if **y** is also greater than **5**. If so, the string **"x and y are > 5"** is output. Otherwise, it *appears* that if **x** is not greater than **5**, the **else** part of the **if/else** structure outputs the string **"x is <= 5"**.

Beware! The preceding nested **if** structure does not execute as it would appear to. The compiler actually interprets the preceding structure as

```
if ( x > 5 )
   if ( y > 5 )
      System.out.println( "x and y are > 5" );
   else
      System.out.println( "x is <= 5" );
```

in which the body of the first **if** structure is an **if/else** structure. This structure tests if **x** is greater than **5**. If so, execution continues by testing if **y** is also greater than **5**. If the second condition is true, the proper string—**"x and y are > 5"**—is displayed. However, if the second condition is false, the string **"x is <= 5"** is displayed, even though we know that **x** is greater than **5**.

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To force the preceding nested **if** structure to execute as it was originally intended, the structure must be written as follows:

```
if ( x > 5 ) {
   if ( y > 5 )
      System.out.println( "x and y are > 5" );
}
else
   System.out.println( "x is <= 5" );
```

The braces (**{}**) indicate to the compiler that the second **if** structure is in the body of the first **if** structure and that the **else** is matched with the first **if** structure. In Exercise 4.21 and Exercise 4.22, you will investigate the dangling-else problem further.

The **if** selection structure normally expects only one statement in its body. To include several statements in the body of an **if** structure, enclose the statements in braces (**{** and **}**). A set of statements contained within a pair of braces is called a *block*.

Software Engineering Observation 4.2

A block can be placed anywhere in a program that a single statement can be placed.

The following example includes a block in the **else** part of an **if**/**else** structure:

```
if ( grade >= 60 )
   System.out.println( "Passed" );
else {
   System.out.println( "Failed" );
   System.out.println( "You must take this course again." );
}
```

In this case, if **grade** is less than 60, the program executes both statements in the body of the **else** and prints

```
Failed.
You must take this course again.
```

Notice the braces surrounding the two statements in the **else** clause. These braces are important. Without the braces, the statement

```
System.out.println( "You must take this course again." );
```

would be outside the body of the **else** part of the **if** structure and would execute regardless of whether the grade is less than 60.

Common Programming Error 4.2

Forgetting one or both of the braces that delimit a block can lead to syntax or logic errors.

Syntax errors (such as when one brace in a block is left out of the program) are caught by the compiler. A *logic error* (such as when both braces in a block are left out of the program) has its effect at execution time. A *fatal logic error* causes a program to fail and terminate prematurely. A *nonfatal logic error* allows a program to continue executing, but the program produces incorrect results.

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Software Engineering Observation 4.3

Just as a block can be placed anywhere a single statement can be placed, it is also possible to have no statement at all (i.e., the empty statement in such places). The empty statement is represented by placing a semicolon (`;`) where a statement would normally be.

Common Programming Error 4.3

Placing a semicolon after the condition in an `if` structure leads to a logic error in single-selection `if` structures and a syntax error in double-selection `if` structures (if the `if` part contains a nonempty body statement).

Good Programming Practice 4.5

Some programmers prefer to type the beginning and ending braces of blocks before typing the individual statements within the braces. This practice helps avoid omitting one or both of the braces.

In this section, we have introduced the notion of a block. A block may contain declarations (as does the body of **`main`**, for example). The declarations in a block commonly are placed first in the block before any action statements occur, but declarations may also be intermixed with action statements.

4.7 The `while` Repetition Structure

A *repetition structure* allows the programmer to specify that an action is to be repeated while some condition remains true. The pseudocode statement

```
While there are more items on my shopping list
    Purchase next item and cross it off my list
```

describes the repetition that occurs during a shopping trip. The condition "there are more items on my shopping list" may be true or false. If it is true, then the action "Purchase next item and cross it off my list" is performed. This action will be performed repeatedly while the condition remains true. The statement(s) contained in the *while* repetition structure constitute the body of the *while* structure. The body of the *while* structure may be a single statement or a block. Eventually, the condition will become false (when the last item on the shopping list has been purchased and crossed off the list). At this point, the repetition terminates, and the first pseudocode statement after the repetition structure is executed.

Common Programming Error 4.4

Not providing in the body of a `while` structure an action that eventually causes the condition in the `while` to become false is a logic error. Normally, such a repetition structure will never terminate—an error called an infinite loop.

Common Programming Error 4.5

Spelling the keyword `while` with an uppercase `W`, as in `While`, is a syntax error. (Remember that Java is a case-sensitive language.) All of Java's reserved keywords, such as `while`, `if` and `else`, contain only lowercase letters.

As an example of a **`while`** structure, consider a program segment designed to find the first power of 2 larger than 1000. Suppose that the **`int`** variable **`product`** has been initialized to **`2`**. When the following **`while`** structure finishes executing, **`product`** contains the result:

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```
int product = 2;

while ( product <= 1000 )
   product = 2 * product;
```

The flowchart in Fig. 4.5 illustrates the flow of control of the preceding **while** repetition structure. Once again, note that, besides small circles and arrows, the flowchart contains only a rectangle symbol and a diamond symbol.

Imagine, again, a deep bin of empty **while** structures that may be stacked and nested with other control structures to form a structured implementation of an algorithm's flow of control. The empty rectangles and diamonds are then filled in with appropriate actions and decisions. The flowchart clearly shows the repetition. The flowline emerging from the rectangle wraps back to the decision, which is tested each time through the loop until the decision eventually becomes false. At this point, the **while** structure is exited, and control passes to the next statement in the program.

When the **while** structure is entered, **product** is 2. Variable **product** is repeatedly multiplied by 2, taking on the values 4, 8, 16, 32, 64, 128, 256, 512 and 1024 successively. When **product** becomes 1024, the condition **product <= 1000** in the **while** structure becomes **false**. This result terminates the repetition, with 1024 as **product**'s final value. Execution continues with the next statement after the **while**. [*Note*: If a **while** structure's condition is initially **false**, the body statement(s) will never be performed.]

4.8 Formulating Algorithms: Case Study 1 (Counter-Controlled Repetition)

To illustrate how algorithms are developed, we solve several variations of a class-averaging problem. Consider the following problem statement:

> *A class of ten students took a quiz. The grades (integers in the range 0 to 100) for this quiz are available to you. Determine the class average on the quiz.*

The class average is equal to the sum of the grades divided by the number of students. The algorithm for solving this problem on a computer must input each of the grades, perform the averaging calculation and print the result.

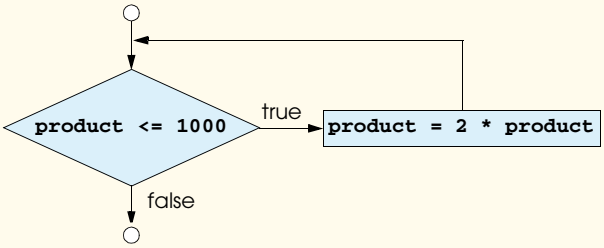

Fig. 4.5 Flowcharting the **while** repetition structure.

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Let us use pseudocode to list the actions to be executed and specify the order in which these actions should be executed. We use *counter-controlled repetition* to input the grades one at a time. This technique uses a variable called a *counter* to control the number of times a set of statements will execute. In this example, repetition terminates when the counter exceeds 10. In this section, we present a pseudocode algorithm (Fig. 4.6) and the corresponding program (Fig. 4.7) to solve this probem using counter-controlled repetition. In the next section, we show how pseudocode algorithms are developed. Counter-controlled repetition is often called *definite repetition*, because the number of repetitions is known before the loop begins executing.

Note the references in the algorithm to a total and a counter. A *total* is a variable used to accumulate the sum of a series of values. A *counter* is a variable used to count—in this case, to count the number of grades entered. Variables used to store totals should normally be initialized to zero before being used in a program; otherwise, the sum would include the previous value stored in the total's memory location.

```
Set total to zero
Set grade counter to one

While grade counter is less than or equal to ten
    Input the next grade
    Add the grade into the total
    Add one to the grade counter

Set the class average to the total divided by ten
Print the class average
```

Fig. 4.6 Pseudocode algorithm that uses counter-controlled repetition to solve the class-average problem.

```
1  // Fig. 4.7: Average1.java
2  // Class average program with counter-controlled repetition.
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class Average1 {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int total,           // sum of grades input by user
13           gradeCounter,    // number of grades entered
14           gradeValue,      // grade value
15           average;         // average of all grades
16       String grade;        // grade typed by user
17
```

Fig. 4.7 Class-average program with counter-controlled repetition (part 1 of 3).

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```
18         // Initialization Phase
19         total = 0;          // clear total
20         gradeCounter = 1;   // prepare to loop
21
22         // Processing Phase
23         while ( gradeCounter <= 10 ) {  // loop 10 times
24
25            // prompt for input and read grade from user
26            grade = JOptionPane.showInputDialog(
27               "Enter integer grade: " );
28
29            // convert grade from a String to an integer
30            gradeValue = Integer.parseInt( grade );
31
32            // add gradeValue to total
33            total = total + gradeValue;
34
35            // add 1 to gradeCounter
36            gradeCounter = gradeCounter + 1;
37
38         }  // end while structure
39
40         // Termination Phase
41         average = total / 10;  // perform integer division
42
43         // display average of exam grades
44         JOptionPane.showMessageDialog( null,
45            "Class average is " + average, "Class Average",
46            JOptionPane.INFORMATION_MESSAGE );
47
48          System.exit( 0 );      // terminate the program
49
50      }  // end method main
51
52   }  // end class Average1
```

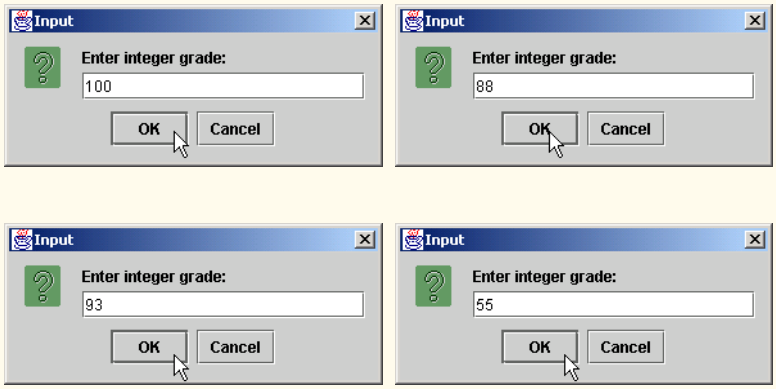

Fig. 4.7 Class-average program with counter-controlled repetition (part 2 of 3).

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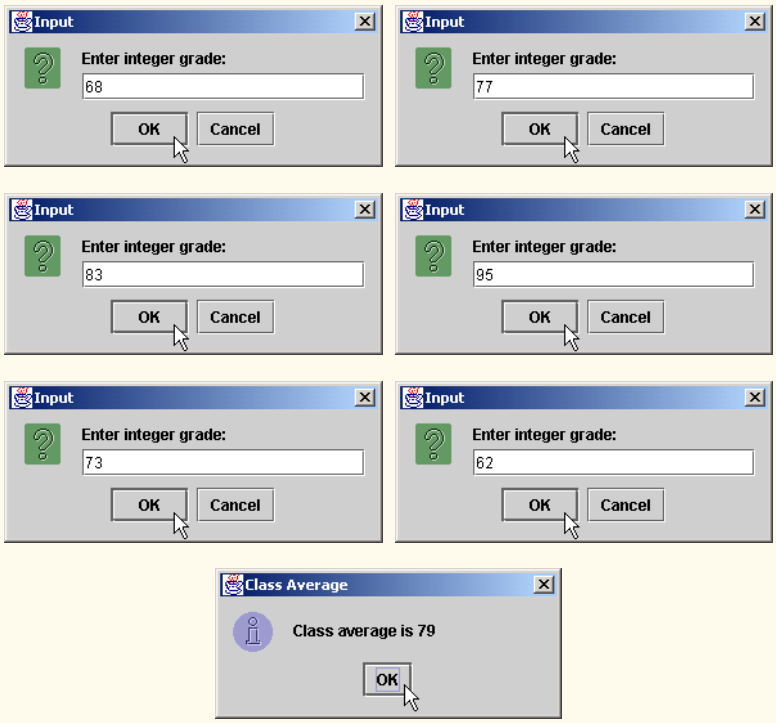

Fig. 4.7 Class-average program with counter-controlled repetition (part 3 of 3).

Good Programming Practice 4.6

Initialize counters and totals.

Line 5,

```
import javax.swing.JOptionPane;
```

imports class **JOptionPane** to enable the program to read data from the keyboard and output data to the screen using the input dialog and message dialog shown in Chapter 2.

Line 7 begins the definition of application class **Average1**. Remember that the definition of an application class must contain a **main** method (lines 10–49) in order for the application to be executed.

Lines 12–16,

```
int total,           // sum of grades
    gradeCounter,    // number of grades entered
    gradeValue,      // grade value
    average;         // average of all grades
String grade;        // grade typed by user
```

declare variables **total**, **gradeCounter**, **gradeValue** and **average** to be of type **int** and variable **grade** to be of type **String**. Variable **grade** stores the **String** the

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user types in the input dialog. Variable **gradeValue** stores the integer value of **grade** after the program converts it from a **String** to an **int**.

Notice that the preceding declarations appear in the body of method **main**. Remember that variables declared in a method definition's body are *local variables* and can be used only from the line of their declaration in the method to the closing right brace (**}**) of the method definition. A local variable's declaration must appear before the variable is used in that method. A local variable declared in one method of a class cannot be accessed directly by other methods of a class.

Good Programming Practice 4.7

Always place a blank line before a declaration that appears between executable statements. This format makes the declarations stand out in the program and contributes to program clarity.

Good Programming Practice 4.8

If you prefer to place declarations at the beginning of a method, separate the declarations from the executable statements in that method with one blank line, to highlight where the declarations end and the executable statements begin.

Common Programming Error 4.6

Attempting to use a local variable's value before initializing the variable (normally with an assignment statement) results in a compile error indicating that the variable may not have been initialized. The value of a local variable cannot be used until the variable is initialized. The program will not compile properly until the variable receives an initial value.

Lines 19–20,

```
total = 0;           // clear total
gradeCounter = 1;    // prepare to loop
```

are assignment statements that initialize **total** to **0** and **gradeCounter** to **1**. Note that these statements initialize variables **total** and **gradeCounter** before they are used in calculations.

Line 23,

```
while ( gradeCounter <= 10 ) {  // loop 10 times
```

indicates that the **while** structure should continue looping (also called *iterating*) as long as the value of **gradeCounter** is less than or equal to 10.

Lines 26–27,

```
grade = JOptionPane.showInputDialog(
   "Enter integer grade: " );
```

correspond to the pseudocode statement "*Input the next grade.*" The statement displays an input dialog with the prompt "**Enter integer grade:**" on the screen.

After the user enters the **grade**, the program converts it from a **String** to an **int** at line 30,

```
gradeValue = Integer.parseInt( grade );
```

Remember that class **Integer** is from package **java.lang** that the compiler imports in every Java program. The pseudocode for the class-average problem does not reflect the pre-

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ceding statement. The pseudocode statement "*Input the next grade*" requires the programmer to implement the process of obtaining the value from the user and converting it to a type that can be used in calculating the average. As you learn to program, you will find that you require fewer pseudocode statements to help you implement a program.

Next, the program updates the **total** with the new **gradeValue** entered by the user. Line 33,

```
total = total + gradeValue;
```

adds **gradeValue** to the previous value of **total** and assigns the result to **total**.

Line 36,

```
gradeCounter = gradeCounter + 1;
```

adds **1** to **gradeCounter** to indicate that the program hasprocessed a grade and is ready to input the next grade from the user. Incrementing **gradeCounter** is necessary for the condition in the **while** structure to become **false** eventually and terminate the loop.

Line 41,

```
average = total / 10;   // perform integer division
```

assigns the results of the average calculation to variable **average**. Lines 44–46,

```
JOptionPane.showMessageDialog(
   null, "Class average is " + average, "Class Average",
   JOptionPane.INFORMATION_MESSAGE );
```

display an information message dialog containing the string **"Class average is "** followed by the value of variable **average**. The string "**Class Average**" (the third argument) is the title of the message dialog.

Line 48,

```
System.exit( 0 );       // terminate the program
```

terminates the application.

After compiling the class definition with **javac**, execute the application from the command window with the command

```
java Average1
```

This command executes the Java interpreter and tells it that the **main** method for this application is defined in class **Average1**.

Note that the averaging calculation in the program produced an integer result. Actually, the sum of the grade-point values in this example is 794, which, when divided by 10, should yield 79.4 (i.e., a number with a decimal point). We will see how to deal with such numbers (called *floating-point numbers*) in the next section.

4.9 Formulating Algorithms with Top-Down, Stepwise Refinement: Case Study 2 (Sentinel-Controlled Repetition)

Let us generalize the class-average problem. Consider the following problem:

> *Develop a class-averaging program that processes an arbitrary number of grades each time the program executes.*

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In the first class-average example, the number of grades (10) was known in advance. In this example, no indication is given of how many grades the user will input. The program must process an arbitrary number of grades. How can the program determine when to stop the input of grades? How will it know when to calculate and print the class average?

One way to solve this problem is to use a special value called a *sentinel value* (also called a *signal value*, a *dummy value* or a *flag value*) to indicate the end of data entry. The user types grades in until all legitimate grades have been entered. The user then types the sentinel value to indicate that the last grade has been entered. Sentinel-controlled repetition is often called *indefinite repetition*, because the number of repetitions is not known before the loop begins executing.

Clearly, the sentinel value must be chosen so that it cannot be confused with an acceptable input value. Because grades on a quiz are normally nonnegative integers, –1 is an acceptable sentinel value for this problem. Thus, an execution of the class-average program might process a stream of inputs such as 95, 96, 75, 74, 89 and –1. In this case, the program would compute and print the class average for the grades 95, 96, 75, 74 and 89. (–1 is the sentinel value, so it should not enter into the averaging calculation.)

Common Programming Error 4.7

Choosing a sentinel value that is also a legitimate data value results in a logic error and may prevent a sentinel-controlled loop from terminating properly.

We approach the class-average program with a technique called *top-down, stepwise refinement*, a method that is essential to the development of well-structured algorithms. We begin with a pseudocode representation of the *top*:

Determine the class average for the quiz

The top is a single statement that conveys the overall function of the program. As such, the top is, in effect, a complete representation of a program. Unfortunately, the top rarely conveys a sufficient amount of detail from which to write the Java algorithm. So we now begin the refinement process. We divide the top into a series of smaller tasks and list these tasks in the order in which they need to be performed. This procedure results in the following *first refinement*:

Initialize variables
Input, sum up and count the quiz grades
Calculate and print the class average

This pseudocode uses only the sequence structure—the steps listed occur in order, one after the other.

Software Engineering Observation 4.4

Each refinement, as well as the top itself, is a complete specification of the algorithm; only the level of detail varies.

To proceed to the next level of refinement (i.e., the *second refinement*), we commit to specific variables. We need a running total of the grades, a count of how many grades have been processed, a variable to receive the value of each grade as it is input and a variable to store the calculated average. The pseudocode statement

Initialize variables

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may be refined as follows:

Initialize total to zero
Initialize counter to zero

Notice that only the variables *total* and *counter* are initialized before they are used; the variables *average* and *grade* (for the calculated average and the user input, respectively) need not be initialized, because their values are replaced as they are calculated or input.

The pseudocode statement

Input, sum up and count the quiz grades

requires a repetition structure (i.e., a loop) that successively inputs each grade. We do not know how many grades the user will input, so the program will use sentinel-controlled repetition. The user at the keyboard inputs legitimate grades one at a time. After inputting the last legitimate grade, the user types the sentinel value. The program tests for the sentinel value after each grade is input and terminates the loop when the user inputs the sentinel value. The second refinement of the preceding pseudocode statement is then

Input the first grade (possibly the sentinel)

While the user has not as yet entered the sentinel
    Add this grade into the running total
    Add one to the grade counter
    Input the next grade (possibly the sentinel)

Notice that in pseudocode, we do not use braces around the pseudocode that forms the body of the *while* structure. We simply indent the pseudocode under the *while*, to show that it belongs to the *while*. Again, pseudocode is only an informal program development aid.

The pseudocode statement

Calculate and print the class average

may be refined as follows:

If the counter is not equal to zero
    Set the average to the total divided by the counter
    Print the average
else
    Print "No grades were entered"

Notice that we are testing for the possibility of division by zero—a *logic error* that, if undetected, would cause the program to produce invalid output. The complete second refinement of the pseudocode algorithm for the class-average problem is shown in Fig. 4.8.

Testing and Debugging Tip 4.1

When performing division by an expression whose value could be zero, explicitly test for this case and handle it appropriately in your program (such as by printing an error message) rather than allowing the division by zero to occur.

Good Programming Practice 4.9

Include completely blank lines in pseudocode programs to make the pseudocode more readable. The blank lines separate pseudocode control structures, as well as the phases of the programs.

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```
Initialize total to zero
Initialize counter to zero

Input the first grade (possibly the sentinel)

While the user has not as yet entered the sentinel
    Add this grade into the running total
    Add one to the grade counter
    Input the next grade (possibly the sentinel)

If the counter is not equal to zero
    Set the average to the total divided by the counter
    Print the average
else
    Print "No grades were entered"
```

Fig. 4.8 Pseudocode algorithm that uses sentinel-controlled repetition to solve the class-average problem.

Software Engineering Observation 4.5

Many algorithms can be divided logically into three phases: an initialization phase that initializes the program variables; a processing phase that inputs data values and adjusts program variables accordingly and a termination phase that calculates and displays the results.

The pseudocode algorithm in Fig. 4.8 solves the more general class-averaging problem. This algorithm was developed after only two levels of refinement. Sometimes more levels are necessary.

Software Engineering Observation 4.6

The programmer terminates the top-down, stepwise refinement process when the pseudocode algorithm is specified in sufficient detail for the programmer to be able to convert the pseudocode to a Java applet or application. Normally, implementing the Java applet or application is then straightforward.

The Java application and a sample execution are shown in Fig. 4.9. Although each grade is an integer, the averaging calculation is likely to produce a number with a decimal point (i.e., a real number). The type **`int`** cannot represent real numbers (i.e., numbers with decimal points), so this program uses data type ***`double`*** to handle floating-point numbers. The program introduces a special operator called a *cast operator* to handle the type conversion we will need for the averaging calculation. These features are explained in detail in the discussion of the application.

In this example, we see that control structures may be stacked on top of one another (in sequence) just as a child stacks building blocks. The **`while`** structure (lines 33–47) is followed by an **`if`**/**`else`** structure (lines 52–63) in sequence. Much of the code in this program is identical to the code in Fig. 4.7, so we concentrate in this example on the new features and issues.

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```
1  // Fig. 4.9: Average2.java
2  // Class average program with sentinel-controlled repetition.
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 public class Average2 {
11
12    // main method begins execution of Java application
13    public static void main( String args[] )
14    {
15       int gradeCounter,  // number of grades entered
16           gradeValue,    // grade value
17           total;         // sum of grades
18       double average;    // average of all grades
19       String input;      // grade typed by user
20
21       // Initialization phase
22       total = 0;         // clear total
23       gradeCounter = 0;  // prepare to loop
24
25       // Processing phase
26       // prompt for input and read grade from user
27       input = JOptionPane.showInputDialog(
28          "Enter Integer Grade, -1 to Quit:" );
29
30       // convert grade from a String to an integer
31       gradeValue = Integer.parseInt( input );
32
33       while ( gradeValue != -1 ) {
34
35          // add gradeValue to total
36          total = total + gradeValue;
37
38          // add 1 to gradeCounter
39          gradeCounter = gradeCounter + 1;
40
41          // prompt for input and read grade from user
42          input = JOptionPane.showInputDialog(
43             "Enter Integer Grade, -1 to Quit:" );
44
45          // convert grade from a String to an integer
46          gradeValue = Integer.parseInt( input );
47       }
48
49       // Termination phase
50       DecimalFormat twoDigits = new DecimalFormat( "0.00" );
51
52       if ( gradeCounter != 0 ) {
53          average = (double) total / gradeCounter;
```

Fig. 4.9 Class-average program with sentinel-controlled repetition (part 1 of 2).

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```
54
55             // display average of exam grades
56             JOptionPane.showMessageDialog( null,
57                "Class average is " + twoDigits.format( average ),
58                "Class Average", JOptionPane.INFORMATION_MESSAGE );
59          }
60          else
61             JOptionPane.showMessageDialog( null,
62                "No grades were entered", "Class Average",
63                JOptionPane.INFORMATION_MESSAGE );
64
65          System.exit( 0 );     // terminate application
66
67       }  // end method main
68
69    }  // end class Average2
```

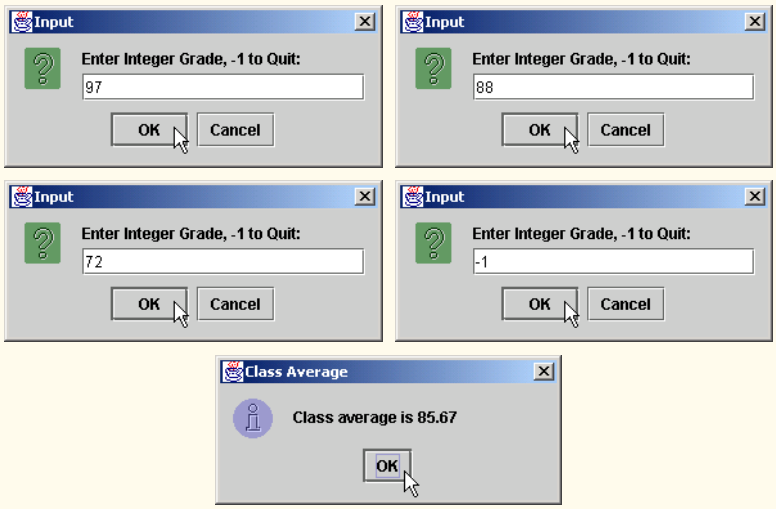

Fig. 4.9 Class-average program with sentinel-controlled repetition (part 2 of 2).

Line 18 declares **double** variable **average**. This change allows us to store the class average as a floating-point number. Line 23 initializes **gradeCounter** to **0**, because no grades have been entered yet. Remember that this program uses sentinel-controlled repetition. To keep an accurate record of the number of grades entered, variable **gradeCounter** is incremented only when the user inputs a valid grade value.

Notice the difference in program logic for sentinel-controlled repetition as compared with the counter-controlled repetition in Fig. 4.7. In counter-controlled repetition, each iteration (loop) of the **while** structure reads a value from the user, for the specified number of iterations. In sentinel-controlled repetition, the program reads and converts one value (lines 27–31) before reaching the **while** structure. This value determines whether the program's flow of control should enter the body of the **while** structure. If the condition of the **while** structure is **false**, the user entered the sentinel, so the body of the **while** structure does not execute (i.e., no grades were entered). If, on the other hand, the condition is **true**, the body begins execution, and the loop adds the value input by the user to the

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total. After the value has been processed, lines 42–46 in the loop's body input the next value from the user before program control reaches the end of the **while** structure's body. As program control reaches the closing right brace (**}**) of the body at line 47, execution continues with the next test of the condition of the **while** structure (line 33). The condition uses the new value just input by the user to determine if the **while** structure's body should execute again. Notice that the next value always is input from the user immediately before the program tests the condition of the **while** structure. This structure allows the program to determine if the value just input by the user is the sentinel value *before* the program processes that value (i.e., adds it to the **total**). If the value input is the sentinel value, the **while** structure terminates, and the program does not add the value to the **total**.

Notice the block in the **while** loop in Fig. 4.9. Without the braces, the last four statements in the body of the loop would fall outside the loop, causing the computer to interpret the code incorrectly as follows:

```
while ( gradeValue != -1 )

   // add gradeValue to total
   total = total + gradeValue;

// add 1 to gradeCounter
gradeCounter = gradeCounter + 1;

// prompt for input and read grade from user
input = JOptionPane.showInputDialog(
   "Enter Integer Grade, -1 to Quit:" );

// convert grade from a String to an integer
gradeValue = Integer.parseInt( input );
```

This code would cause an infinite loop in the program if the user does not input the sentinel **-1** as the input value at lines 27–28 (before the **while** structure) in the program.

Common Programming Error 4.8

Omitting the curly braces that are needed to delineate a block can lead to logic errors such as infinite loops. To prevent this problem, some programmers enclose the body of every control structure in braces.

Good Programming Practice 4.10

In a sentinel-controlled loop, the prompts requesting data entry should explicitly remind the user of the value that represents the sentinel.

Line 50,

```
DecimalFormat twoDigits = new DecimalFormat( "0.00" );
```

declares **twoDigits** as a reference to an object of class ***DecimalFormat*** (package ***java.text***). **DecimalFormat** objects format numbers. In this example, we want to output the class average with two digits to the right of the decimal point (i.e., rounded to the nearest hundredth). The preceding line creates a **DecimalFormat** object that is initialized with the string **"0.00"**. Each **0** is a *format flag* that specifies a required digit position in the formatted floating-point number. This particular format indicates that every number formatted with **twoDigits** will have at least one digit to the left of the decimal point and exactly two digits to the right of the decimal point. If the number does not meet the formatting requirements, **0**s are inserted in the formatted number at the required positions. The ***new*** *operator* creates an

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object as the program executes by obtaining enough memory to store an object of the type specified to the right of **new**. The process of creating new objects is also known as *creating an instance*, or *instantiating an object.* Operator **new** is known as the *dynamic memory allocation operator*. The value in parentheses after the type in a **new** operation is used to *initialize* (i.e., give a value to) the new object. Reference **twoDigits** is assigned the result of the **new** operation by using the *assignment operator,* **=**. The statement is read as "**twoDigits** *gets* the value of **new DecimalFormat("0.00")**."

Software Engineering Observation 4.7

Normally, objects are created with operator ***new****. One exception to this is a string literal that is contained in quotes, such as* ***"hello"****. String literals are treated as objects of class* ***String*** *and are instantiated automatically.*

Averages do not always evaluate to integer values. Often, an average is a value that contains a fractional part, such as 3.333 or 2.7. These values are referred to as *floating-point numbers* and are represented by the data type **double**. The variable **average** is declared to be of type **double** to capture the fractional result of our calculation. However, the result of the calculation **total / gradeCounter** is an integer, because **total** and **gradeCounter** are both integer variables. Dividing two integers results in *integer division*—any fractional part of the calculation is lost (i.e., *truncated*). The fractional part of the calculation is lost before the result can be assigned to **average**, because the calculation is performed before the assignment occurs.

To perform a floating-point calculation with integer values, we must create temporary values that are floating-point numbers for the calculation. Java provides the *unary cast operator* to accomplish this task. Line 53,

```
average = (double) total / gradeCounter;
```

uses the cast operator ***(double)*** to create a temporary floating-point copy of its operand—**total**. Using a cast operator in this manner is called *explicit conversion*. The value stored in **total** is still an integer. The calculation now consists of a floating-point value (the temporary **double** version of **total**) divided by the integer **gradeCounter**. Java knows how to evaluate only arithmetic expressions in which the operands' data types are identical. To ensure that the operands are of the same type, Java performs an operation called *promotion* (or *implicit conversion*) on selected operands. For example, in an expression containing the data types **int** and **double**, the values of **int** operands are *promoted* to **double** values for use in the expression. In this example, Java promotes the value of **gradeCounter** to type **double**, and then the program performs the calculation and assigns the result of the floating-point division to **average**. Later in this chapter, we discuss all of the standard data types and their order of promotion.

Common Programming Error 4.9

The cast operator can be used to convert between primitive numeric types and to convert between related class types (as we discuss in Chapter 9). Casting a variable to the wrong type may cause compilation errors or runtime errors.

Cast operators are available for any data type. The cast operator is formed by placing parentheses around the name of a data type. The operator is a *unary operator* (i.e., an operator that takes only one operand). In Chapter 2, we studied the binary arithmetic operators. Java also supports unary versions of the plus (**+**) and minus (**-**) operators, so the pro-

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grammer can write expressions like `-7` or `+5`. Cast operators associate from right to left and have the same precedence as other unary operators, such as unary `+` and unary `-`. This precedence is one level higher than that of the *multiplicative operators* `*`, `/` and `%` and one level lower than that of parentheses. (See the operator precedence chart in Appendix C.) We indicate the cast operator with the notation `(`*type*`)` in our precedence charts, to indicate that any type name can be used to form a cast operator.

Common Programming Error 4.10

Using floating-point numbers in a manner that assumes they are represented precisely can lead to incorrect results. Floating-point numbers are represented approximately by computers.

Common Programming Error 4.11

Assuming that integer division rounds (rather than truncates) can lead to incorrect results.

Good Programming Practice 4.11

Do not compare floating-point values for equality or inequality. Rather, test for whether the absolute value of the difference between two floating-point numbers is less than a specified small value.

Despite the fact that floating-point numbers are not always 100% precise, they have numerous applications. For example, when we speak of a "normal" body temperature of 98.6, we do not need to be precise to a large number of digits. When we view the temperature on a thermometer and read it as 98.6, it may actually be 98.5999473210643. The point here is that calling this number simply 98.6 is fine for most applications.

Another way in which floating-point numbers develop is through division. When we divide 10 by 3, the result is 3.3333333…, with the sequence of 3s repeating infinitely. The computer allocates only a fixed amount of space to hold such a value, so clearly the stored floating-point value can be only an approximation.

4.10 Formulating Algorithms with Top-Down, Stepwise Refinement: Case Study 3 (Nested Control Structures)

Let us work through another complete problem. We once again formulate the algorithm using pseudocode and top-down, stepwise refinement, and we develop a corresponding Java program. Consider the following problem statement:

> *A college offers a course that prepares students for the state licensing exam for real estate brokers. Last year, several of the students who completed this course took the licensing examination. Naturally, the college wants to know how well its students did on the exam. You have been asked to write a program to summarize the results. You have been given a list of these 10 students. Next to each name is written a 1 if the student passed the exam and a 2 if the student failed.*
>
> *Your program should analyze the results of the exam as follows:*
>
> 1. *Input each test result (i.e., a 1 or a 2). Display the message "Enter result" on the screen each time the program requests another test result.*
> 2. *Count the number of test results of each type.*
> 3. *Display a summary of the test results indicating the number of students who passed and the number of students who failed.*
> 4. *If more than 8 students passed the exam, print the message "Raise tuition."*

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After reading the problem statement carefully, we make the following observations about the problem:

1. The program must process test results for 10 students. A counter-controlled loop will be used.
2. Each test result is a number—either a 1 or a 2. Each time the program reads a test result, the program must determine if the number is a 1 or a 2. We test for a 1 in our algorithm. If the number is not a 1, we assume that it is a 2. (An exercise at the end of the chapter considers the consequences of this assumption.)
3. Two counters are used to keep track of the exam results—one to count the number of students who passed the exam and one to count the number of students who failed the exam.
4. After the program has processed all the results, it must decide if more than eight students passed the exam.

Let us proceed with top-down, stepwise refinement. We begin with a pseudocode representation of the top:

Analyze exam results and decide if tuition should be raised

Once again, it is important to emphasize that the top is a complete representation of the program, but several refinements are likely before the pseudocode can evolve naturally into a Java program. Our first refinement is

Initialize variables
Input the ten exam grades and count passes and failures
Print a summary of the exam results and decide if tuition should be raised

Here, too, even though we have a complete representation of the entire program, further refinement is necessary. We now commit to specific variables. We need counters to record the passes and failures, a counter to control the looping process and a variable to store the user input. The pseudocode statement

Initialize variables

may be refined as follows:

Initialize passes to zero
Initialize failures to zero
Initialize student to one

Notice that only the counters for the number of passes, number of failures and number of students are initialized. The pseudocode statement

Input the ten quiz grades and count passes and failures

requires a loop that successively inputs the result of each exam. Here it is known in advance that there are precisely ten exam results, so counter-controlled looping is appropriate. Inside the loop (i.e., *nested* within the loop) a double-selection structure determines whether each exam result is a pass or a failure and increments the appropriate counter accordingly. The refinement of the preceding pseudocode statement is:

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```
While student counter is less than or equal to ten
    Input the next exam result

    If the student passed
        Add one to passes
    else
        Add one to failures

    Add one to student counter
```

Notice the use of blank lines to set off the *if/else* control structure to improve program readability. The pseudocode statement

```
Print a summary of the exam results and decide if tuition should be raised
```

may be refined as follows:

```
Print the number of passes
Print the number of failures

If more than eight students passed
    Print "Raise tuition"
```

The complete second refinement appears in Fig. 4.10. Notice that the pseudocode also uses blank lines to set off the *while* structure for program readability.

```
Initialize passes to zero
Initialize failures to zero
Initialize student to one

While student counter is less than or equal to ten
    Input the next exam result

    If the student passed
        Add one to passes
    else
        Add one to failures

    Add one to student counter

Print the number of passes
Print the number of failures

If more than eight students passed
    Print "Raise tuition"
```

Fig. 4.10 Pseudocode for examination-results problem.

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This pseudocode is now sufficiently refined for conversion to Java. The Java program and two sample executions are shown in Fig. 4.11.

```
1  // Fig. 4.11: Analysis.java
2  // Analysis of examination results.
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class Analysis {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       // initializing variables in declarations
13       int passes = 0,              // number of passes
14           failures = 0,            // number of failures
15           student = 1,             // student counter
16           result;                  // one exam result
17       String input,                // user-entered value
18              output;               // output string
19
20       // process 10 students; counter-controlled loop
21       while ( student <= 10 ) {
22
23          // obtain result from user
24          input = JOptionPane.showInputDialog(
25             "Enter result (1=pass,2=fail)" );
26
27          // convert result to int
28          result = Integer.parseInt( input );
29
30          // process result
31          if ( result == 1 )
32             passes = passes + 1;
33          else
34             failures = failures + 1;
35
36          student = student + 1;
37       }
38
39       // termination phase
40       output = "Passed: " + passes +
41          "\nFailed: " + failures;
42
43       if ( passes > 8 )
44          output = output + "\nRaise Tuition";
45
46       JOptionPane.showMessageDialog( null, output,
47          "Analysis of Examination Results",
48          JOptionPane.INFORMATION_MESSAGE );
49
50       System.exit( 0 );  // terminate application
```

Fig. 4.11 Java program for examination-results problem (part 1 of 2).

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```
51
52       }  // end method main
53
54    }  // end class Analysis
```

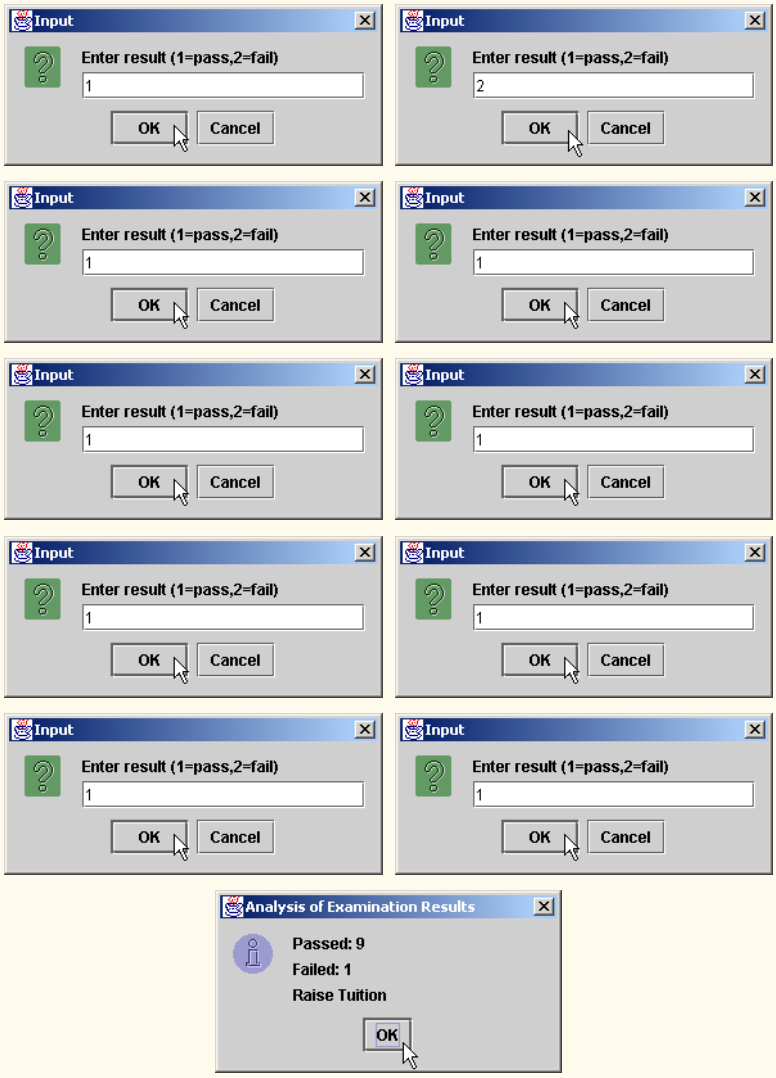

Fig. 4.11 Java program for examination-results problem (part 2 of 2).

Lines 13–18,

```
int passes = 0,              // number of passes
    failures = 0,            // number of failures
    student = 1,             // student counter
    result;                  // one exam result
String input,                // user-entered value
       output;               // output string
```

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declare the variables used in **main** to process the examination results. Note that we have taken advantage of a feature of Java that incorporates variable initialization into declarations (**passes** is assigned **0**, **failures** is assigned **0** and **student** is assigned **1**). Looping programs may require initialization at the beginning of each repetition; such initialization would normally occur in assignment statements.

Notice the nested **if/else** structure at lines 31–34 of the **while** structure's body. Also, notice the use of **String** reference **output** in lines 40, 41 and 44 to build the string that lines 46–48 display in a message dialog.

Good Programming Practice 4.12

Initializing local variables when they are declared in methods helps the programmer avoid compiler messages warning of uninitialized data.

Software Engineering Observation 4.8

Experience has shown that the most difficult part of solving a problem on a computer is developing the algorithm for the solution. Once a correct algorithm has been specified, the process of producing a working Java program from the algorithm is normally straightforward.

Software Engineering Observation 4.9

Many experienced programmers write programs without ever using program development tools like pseudocode. These programmers feel that their ultimate goal is to solve the problem on a computer and that writing pseudocode merely delays the production of final outputs. Although this method may work for simple and familiar problems, it can lead to serious errors in large, complex projects.

4.11 Assignment Operators

Java provides several assignment operators for abbreviating assignment expressions. For example, you can abbreviate the statement

```
c = c + 3;
```

with the *addition assignment operator*, **+=**, as

```
c += 3;
```

The **+=** operator adds the value of the expression on the right of the operator to the value of the variable on the left of the operator and stores the result in the variable on the left of the operator. Any statement of the form

variable **=** *variable operator expression***;**

where *operator* is one of the binary operators **+**, **-**, *****, **/** or **%** (or others we discuss later in the text), can be written in the form

*variable operator***=** *expression***;**

Thus, the assignment expression **c += 3** adds **3** to **c**. Figure 4.12 shows the arithmetic assignment operators, sample expressions using the operators and explanations of what the operators do.

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Assignment operator	Sample expression	Explanation	Assigns
Assume: `int c = 3, d = 5, e = 4, f = 6, g = 12;`			
`+=`	`c += 7`	`c = c + 7`	`10` to `c`
`-=`	`d -= 4`	`d = d - 4`	`1` to `d`
`*=`	`e *= 5`	`e = e * 5`	`20` to `e`
`/=`	`f /= 3`	`f = f / 3`	`2` to `f`
`%=`	`g %= 9`	`g = g % 9`	`3` to `g`

Fig. 4.12 Arithmetic assignment operators.

Performance Tip 4.1

Programmers can write programs a bit faster and compilers can compile programs a bit faster when the abbreviated assignment operators are used. Some compilers generate code that runs faster when abbreviated assignment operators are used.

Performance Tip 4.2

Many of the performance tips we mention in this text result in nominal improvements, so the reader may be tempted to ignore them. Significant performance improvement is often realized when a supposedly nominal improvement is placed in a loop that may repeat a large number of times.

4.12 Increment and Decrement Operators

Java provides the unary *increment operator*, **`++`**, and the unary *decrement operator*, **`--`**, which are summarized in Fig. 4.13. A program can increment the value of a variable called **`c`** by 1 using the increment operator, **`++`**, rather than the expression **`c = c + 1`** or **`c += 1`**. If an increment or decrement operator is placed before a variable, it is referred to as the *preincrement* or *predecrement operator*, respectively. If an increment or decrement operator is placed after a variable, it is referred to as the *postincrement* or *postdecrement operator*, respectively.

Operator	Called	Sample expression	Explanation
`++`	preincrement	`++a`	Increment **`a`** by 1, then use the new value of **`a`** in the expression in which **`a`** resides.
`++`	postincrement	`a++`	Use the current value of **`a`** in the expression in which **`a`** resides, then increment **`a`** by 1.
`--`	predecrement	`--b`	Decrement **`b`** by 1, then use the new value of **`b`** in the expression in which **`b`** resides.
`--`	postdecrement	`b--`	Use the current value of **`b`** in the expression in which **`b`** resides, then decrement **`b`** by 1.

Fig. 4.13 The increment and decrement operators .

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Preincrementing (predecrementing) a variable causes the variable to be incremented (decremented) by 1, and then the new value of the variable is used in the expression in which it appears. Postincrementing (postdecrementing) the variable causes the current value of the variable to be used in the expression in which it appears, and then the variable value is incremented (decremented) by 1.

The application in Fig. 4.14 demonstrates the difference between the preincrementing version and the postincrementing version of the **++** increment operator. Postincrementing the variable **c** causes it to be incremented after it is used in the **System.out.println** method call (line 13). Preincrementing the variable **c** causes it to be incremented before it is used in the **System.out.println** method call (line 20).

The program displays the value of **c** before and after the **++** operator is used. The decrement operator (**--**) works similarly.

Good Programming Practice 4.13

Unary operators should be placed next to their operands, with no intervening spaces.

```
1  // Fig. 4.14: Increment.java
2  // Preincrementing and postincrementing
3
4  public class Increment {
5
6     // main method begins execution of Java application
7     public static void main( String args[] )
8     {
9        int c;
10
11       c = 5;
12       System.out.println( c );   // print 5
13       System.out.println( c++ ); // print 5 then postincrement
14       System.out.println( c );   // print 6
15
16       System.out.println();      // skip a line
17
18       c = 5;
19       System.out.println( c );   // print 5
20       System.out.println( ++c ); // preincrement then print 6
21       System.out.println( c );   // print 6
22
23    }  // end method main
24
25 }  // end class Increment
```

```
5
5
6

5
6
6
```

Fig. 4.14 The difference between preincrementing and postincrementing.

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Line 16,

```
System.out.println();       // skip a line
```

uses **System.out.println** to output a blank line. If **println** receives no arguments, it simply outputs a newline character.

The arithmetic assignment operators and the increment and decrement operators can be used to simplify program statements. For example, the three assignment statements in Fig. 4.11 (lines 32, 34 and 36),

```
passes = passes + 1;
failures = failures + 1;
student = student + 1;
```

can be written more concisely with assignment operators as

```
passes += 1;
failures += 1;
student += 1;
```

with preincrement operators as

```
++passes;
++failures;
++student;
```

or with postincrement operators as

```
passes++;
failures++;
student++;
```

It is important to note here that when incrementing or decrementing a variable in a statement by itself, the preincrement and postincrement forms have the same effect, and the predecrement and postdecrement forms have the same effect. It is only when a variable appears in the context of a larger expression that preincrementing and post-incrementing the variable have different effects (and similarly for predecrementing and postdecrementing).

Common Programming Error 4.12

Attempting to use the increment or decrement operator on an expression other than an lvalue *is a syntax error. An* lvalue *is a variable or expression that can appear on the left side of an assignment operation. For example, writing* ***++(x + 1)*** *is a syntax error, because* ***(x + 1)*** *is not an* lvalue.

The chart in Fig. 4.15 shows the precedence and associativity of the operators that have been introduced up to this point. The operators are shown from top to bottom in decreasing order of precedence. The second column describes the associativity of the operators at each level of precedence. Notice that the conditional operator (**?:**), the unary operators increment (**++**), decrement (**--**), plus (**+**), minus (**-**) and casts and the assignment operators **=**, **+=**, **-=**, ***=**, **/=** and **%=** associate from right to left. All other operators in the operator precedence chart in Fig. 4.15 associate from left to right. The third column names the groups of operators.

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Operators	Associativity	Type
`()`	left to right	parentheses
`++ --`	right to left	unary postfix
`++ -- + - (type)`	right to left	unary
`* / %`	left to right	multiplicative
`+ -`	left to right	additive
`< <= > >=`	left to right	relational
`== !=`	left to right	equality
`?:`	right to left	conditional
`= += -= *= /= %=`	right to left	assignment

Fig. 4.15 Precedence and associativity of the operators discussed so far.

4.13 Primitive Data Types

The table in Fig. 4.16 lists the primitive data types in Java. The primitive types are the building blocks for more complicated types. Like its predecessor languages C and C++, Java requires all variables to have a type before they can be used in a program. For this reason, Java is referred to as a *strongly typed language*.

In C and C++ programs, programmers frequently had to write separate versions of programs to support different computer platforms, because the primitive data types were not guaranteed to be identical from computer to computer. For example, an **`int`** value on one machine might be represented by 16 bits (2 bytes) of memory, while an **`int`** value on another machine might be represented by 32 bits (4 bytes) of memory. In Java, **`int`** values are always 32 bits (4 bytes).

Portability Tip 4.1

Unlike in the programming languages C and C++, the primitive types in Java are portable across all computer platforms that support Java. This and many other portability features of Java enable programmers to write programs once, without knowing which computer platform will execute the program. This attribute is sometimes referred to as WORA *(Write Once Run Anywhere).*

Each data type in Fig. 4.16 is listed with its size in bits (there are eight bits to a byte) and its range of values. Because the designers of Java want it to be maximally portable, they chose to use internationally recognized standards for both character formats (Unicode) and floating-point numbers (IEEE 754).

When instance variables of the primitive data types are declared in a class, they are automatically assigned default values unless specified otherwise by the programmer. Instance variables of types **`char`**, **`byte`**, **`short`**, **`int`**, **`long`**, **`float`** and **`double`** are all given the value **`0`** by default. Variables of type **`boolean`** are given the value **`false`** by default.

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Type	Size in bits	Values	Standard
`boolean`	8	`true` or `false`	
`char`	16	`'\u0000'` to `'\uFFFF'` (0 to 65535)	(ISO Unicode character set)
`byte`	8	–128 to +127 (-2^7 to $2^7 - 1$)	
`short`	16	–32,768 to +32,767 (-2^{15} to $2^{15} - 1$)	
`int`	32	–2,147,483,648 to +2,147,483,647 (-2^{31} to $2^{31} - 1$)	
`long`	64	–9,223,372,036,854,775,808 to +9,223,372,036,854,775,807 (-2^{63} to $2^{63} - 1$)	
`float`	32	*Negative range:* –3.4028234663852886E+38 to –1.40129846432481707e–45 *Positive range:* 1.40129846432481707e–45 to 3.4028234663852886E+38	(IEEE 754 floating point)
`double`	64	*Negative range:* –1.7976931348623157E+308 to –4.94065645841246544e–324 *Positive range:* 4.94065645841246544e–324 to 1.7976931348623157E+308	(IEEE 754 floating point)

Fig. 4.16 The Java primitive data types.

4.14 (Optional Case Study) Thinking About Objects: Identifying Class Attributes

In "Thinking About Objects," Section 3.8, we began the first phase of an object-oriented design (OOD) for our elevator simulator—identifying the classes needed to implement the simulator. We began by listing the nouns in the problem statement and then created a separate class for each category of noun and noun phrase that perform an important duty in the elevator simulation. We then represented the classes and their relationships in a UML class diagram (Fig. 3.23). Classes have *attributes* (data) and *operations* (behaviors). Class attributes are implemented in Java programs as variables; class behaviors are implemented as methods. In this section, we determine many of the class attributes needed to implement the elevator simulator. In Chapter 5, we examine how these attributes represent an object's *state*, or condition. In Chapter 6, we determine class behavior. In Chapter 7, we concentrate on the interactions, often called *collaborations*, between the objects in the elevator simulator.

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Consider the attributes of some real-world objects: A person's attributes include height and weight, for example. A radio's attributes include its station setting, its volume setting and whether it is set to AM or FM. A car's attributes include its speedometer and odometer readings, the amount of gas in its tank, what gear it is in, etc. A personal computer's attributes include its manufacturer (e.g., Sun, Apple, IBM or Compaq), type of screen (e.g., monochrome or color), main memory size (in megabytes), hard disk size (in gigabytes), etc.

We can identify the attributes of the classes in our system by looking for descriptive words and phrases in the problem statement. For each descriptive word or phrase we find, we create an attribute and assign that attribute to a class. We also create attributes to represent any additional data that a class may need (as the need for this data becomes clear throughout the design process).

We begin examining the problem statement looking for attributes distinct to each class. Figure 4.17 lists the words or phrases from the problem statement that describe each class. The sentence "The user can create any number of people in the simulation" implies that the model will introduce several **`Person`** objects during execution. We require an integer value representing the number of people in the simulation at any given time, because we may wish to track, or identify, the people in our model. As mentioned in Section 2.9, the **`ElevatorModel`** object acts as the "representative" for the model (even though the model consists of several classes) for interactions with other parts of the system (in this case, the user is a part of the system), so we assign the **`numberOfPeople`** attribute to class **`ElevatorModel`**.

Class **`Elevator`** contains several attributes. The phrases "is moving" and "is summoned" describe possible states of **`Elevator`** (we introduce states in the next "Thinking About Objects" section), so we include **`moving`** and **`summoned`** as **`boolean`** attributes. **`Elevator`** also arrives at a "destination floor," so we include the attribute **`destinationFloor`**, representing the **`Floor`** at which the **`Elevator`** will arrive. Although the problem statement does not mention explicitly that the **`Elevator`** leaves from a current **`Floor`**, we may assume another attribute called **`currentFloor`** representing on which **`Floor`** the **`Elevator`** is resting. The problem statement specifies that "both the elevator and each floor have capacity for only one person," so we include the capacity attribute for class **`Elevator`** (and class **`Floor`**) and set the value to **`1`**. Lastly, the problem statement specifies that the elevator "takes five seconds to travel between floors," so we introduce the **`travelTime`** attribute and set the value to **`5`**.

Class **`Person`** contains several attributes. The user must be able to "create a unique person," which implies that each **`Person`** object should have a unique identifier. We assign integer attribute **`ID`** to the **`Person`** object. The **`ID`** attribute helps to identify that **`Person`** object. In addition, the problem statement specifies that the **`Person`** can be "waiting on that floor to enter the elevator." Therefore, "waiting" is a state that **`Person`** object may enter. Though not mentioned explicitly, if the **`Person`** is not waiting for the **`Elevator`**, the **`Person`** is moving to (or away from) the **`Elevator`**. We assign the **`boolean`** attribute **`moving`** to class **`Person`**. When this attribute is set to **`false`**, the **`Person`** is "waiting." Lastly, the phrase "on that floor" implies that the **`Person`** occupies a floor. We cannot assign a **`Floor`** reference to class **`Person`**, because we are interested only in attributes. However, we want to include the location of the **`Person`** object in the model, so we include the **`currentFloor`** attribute, which may have a value of either **`1`** or **`2`**.

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Class **Floor** has a **capacity** attribute. The problem statement specified that the user could situate the person on either "the first or second floor"—therefore, a **Floor** object requires a value that distinguishes that **Floor** object as the first or second floor, so we include the **floorNumber** attribute.

According to the problem statement, the **ElevatorButton** and **FloorButton** are "pressed" by a **Person**. The buttons may be "reset" as well. The state of each button is either "pressed" or "reset." We include the **boolean** attribute **pressed** in both button classes. When **pressed** is **true**, the button object is pressed; when **pressed** is **false**, the button object is reset. Classes **ElevatorDoor** and **FloorDoor** exhibit similar characteristics. Both objects are either "open" or "closed," so we include the **boolean** attribute **open** in both door classes. Class **Light** also falls into this category—the light is either "illuminated" (turned on) or "turned off," so we include the **boolean** attribute **on** in class **Light**. Note that although the problem statement mentions that the bell rings, there is no mention of when the bell "is ringing," so we do not include a separate **ring** attribute for class **Bell**. As we progress through this case study, we will continue to add, modify and delete information about the classes in our system.

Class	Descriptive words and phrases
ElevatorModel	number of people in the simulation
ElevatorShaft	[no descriptive words or phrases]
Elevator	moving summoned current floor destination floor capacity of only one person five seconds to travel between floors
Person	unique waiting / moving current floor
Floor	first or second; capacity for only one person
FloorButton	pressed / reset
ElevatorButton	pressed / reset
FloorDoor	door closed / door open
ElevatorDoor	door closed / door open
Bell	[no descriptive words or phrases]
Light	illuminated / turned off

Fig. 4.17 Descriptive words and phrases from problem statement.

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Figure 4.18 is a class diagram that lists some of the attributes for each class in our system—the descriptive words and phrases in Fig. 4.17 help us generate these attributes. Note that Fig. 4.18 does not show associations among objects—we showed these associations in Fig. 3.23. In the UML class diagram, a class's attributes are placed in the middle compartment of the class's rectangle. Consider the **open** attribute of class **ElevatorDoor**:

```
open : Boolean = false
```

This listing contains three pieces of information about the attribute. The *attribute name* is **open**. The *attribute type* is **Boolean**.[2] The type depends on the language used to write the software system. In Java, for example, the value can be a *primitive type*, such as **boolean** or **float**, as well as a user-defined type like a class—we begin our study of classes in Chapter 8, where we will see that each new class is a new data type.

We can also indicate an initial value for each attribute. The **open** attribute in class **ElevatorDoor** has an initial value of **false**. If a particular attribute has no initial value specified, only its name and type (separated by a colon) are shown. For example, the **ID** attribute of class **Person** is an integer—in Java, the **ID** attribute is of type **int**. Here we show no initial value, because the value of this attribute is a number that we do not yet know; this number will be determined by **ElevatorModel** at execution time. Integer attribute **currentFloor** for class **Person** is not determined until program execution as well—this attribute is determined when the simulation user decides on which **Floor** to place the **Person**. For now we do not concern ourselves with the types or initial values of the attributes. We include only the information we can glean easily from the problem statement.

Note that Fig. 4.18 does not include attributes for class **ElevatorShaft**. Actually, class **ElevatorShaft** contains seven attributes that we can determine from the class diagram of Fig. 3.23—references to the **Elevator** object, two **FloorButton** objects, two **FloorDoor** objects and two **Light** objects. Class **ElevatorModel** contains three user-defined attributes—two references to **Floor** objects and a reference to the **ElevatorShaft** object. Class **Elevator** also contains three user-defined attributes—reference to the **ElevatorButton** object, the **ElevatorDoor** object and the **Bell** object. To save space, we will not show these additional attributes in our class diagrams—we will, however, include them in the code in the appendices.

The class diagram of Fig. 4.18 provides a good basis for the structure of our model but the diagram is not fully complete. For example, the attribute **currentFloor** in class **Person** represents the floor on which a person is currently located. However, on what floor is the person when that person rides the elevator? These attributes do not yet sufficiently represent the structure of the model. As we present more of the UML and object-oriented design through Chapter 22, we will continue to strengthen the structure of our model.

2. Note that the attribute types in Fig. 4.18 are in UML notation. We will associate the attribute types **Boolean** and **Integer** in the UML diagram with the attribute types **boolean** and **int** in Java, respectively. We described in Chapter 3 that Java provides a "type-wrapper class" for each primitive data type. The Java type-wrapper classes have the same notation as the UML notation for attribute types; however, when we implement our design in Java starting in Chapter 8, we use primitive data types for simplification. Deciding whether to use primitive data types or type-wrapper classes is an implementation-specific issue that should not be mentioned in the UML.

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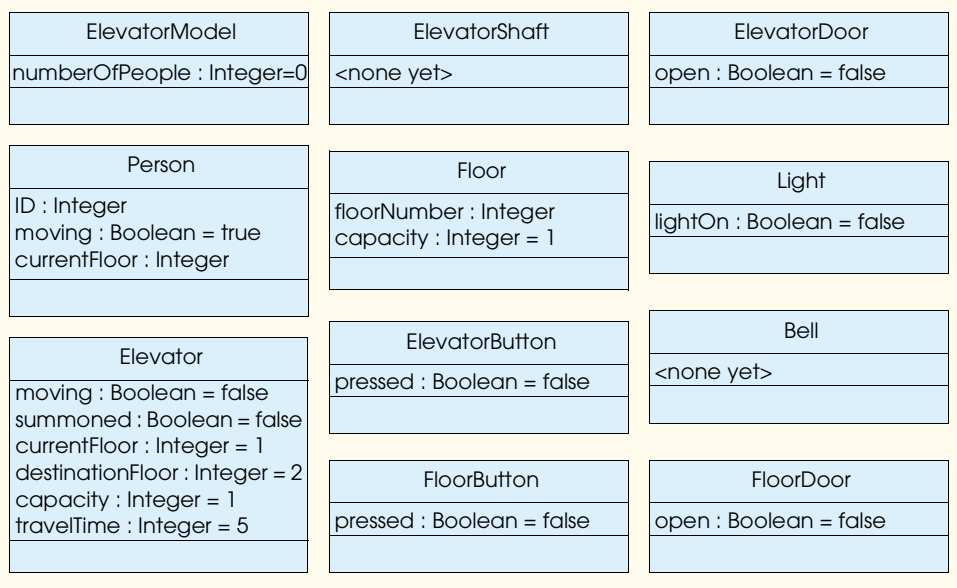

Fig. 4.18 Classes with attributes.

SUMMARY

- A procedure for solving a problem in terms of the actions to be executed and the order in which the actions should be executed is called an algorithm.
- Specifying the order in which statements execute in a computer program is called program control.
- Pseudocode helps the programmer "think out" a program before attempting to write it in a programming language, such as Java.
- Top-down, stepwise refinement is a process for refining pseudocode by maintaining a complete representation of the program during each refinement.
- Declarations are messages to the compiler telling it the names and attributes of variables and telling it to reserve space for variables.
- A selection structure chooses among alternative courses of action.
- The **`if`** selection structure executes an indicated action only when the condition is true.
- The **`if/else`** selection structure specifies separate actions to execute when the condition is true and when the condition is false.
- When more than one statement should execute where normally only a single statement appears, the statements must be enclosed in braces, forming a block. A block can be placed anywhere a single statement can be placed.
- An empty statement, indicating that no action is to be taken, is indicated by placing a semicolon (**`;`**) where a statement would normally be.
- A repetition structure specifies that an action is to be repeated while some condition remains true.
- The format for the **`while`** repetition structure is

```
while ( condition )
    statement
```

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- A value that contains a fractional part is referred to as a floating-point number and is represented by the data type **`float`** or **`double`**.
- Unary cast operator **`(double)`** creates a temporary floating-point copy of its operand.
- Java provides the arithmetic assignment operators **`+=`**, **`-=`**, **`*=`**, **`/=`** and **`%=`**, which help abbreviate certain common types of expressions.
- The increment operator, **`++`**, and the decrement operator, **`--`**, increment or decrement a variable by 1, respectively. If the operator is prefixed to the variable, the variable is incremented or decremented by 1 first, and then used in its expression. If the operator is postfixed to the variable, the variable is used in its expression, and then incremented or decremented by 1.
- The primitive types (**`boolean`**, **`char`**, **`byte`**, **`short`**, **`int`**, **`long`**, **`float`** and **`double`**) are the building blocks for more complicated types in Java.
- Java requires all variables to have a type before they can be used in a program. For this reason, Java is referred to as a strongly typed language.
- Primitive types in Java are portable across all computer platforms that support Java.
- Java uses internationally recognized standards for both character formats (Unicode) and floating-point numbers (IEEE 754).
- Instance variables of types **`char`**, **`byte`**, **`short`**, **`int`**, **`long`**, **`float`** and **`double`** are all given the value **`0`** by default. Variables of type **`boolean`** are given the value **`false`** by default.

TERMINOLOGY

`--` operator
`?:` operator
`++` operator
action
action/decision model
algorithm
arithmetic assignment operators:
`+=`, **`-=`**, **`*=`**, **`/=`** and **`%=`**
block
body of a loop
cast operator, **`(`** *type* **`)`**
conditional operator (**`?:`**)
control structure
counter-controlled repetition
decision
decrement operator (**`--`**)
definite repetition
`double`
double-selection structure
empty statement (**`;`**)
`if` selection structure
`if`/**`else`** selection structure
implicit conversion
increment operator (**`++`**)
indefinite repetition
infinite loop
initialization
integer division
ISO Unicode character set
logic error
loop counter
loop-continuation condition
nested control structures
postdecrement operator
postincrement operator
predecrement operator
preincrement operator
promotion
pseudocode
repetition
repetition structures
selection
sentinel value
sequential execution
single-entry/single-exit control structures
single-selection structure
stacked control structures
structured programming
syntax error
top-down, stepwise refinement
unary operator
`while` repetition structure
white-space characters

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SELF-REVIEW EXERCISES

4.1 Fill in the blanks in each of the following statements:

a) All programs can be written in terms of three types of control structures: _____, _____ and _____.

b) The _____ selection structure is used to execute one action when a condition is true and another action when that condition is false.

c) Repeating a set of instructions a specific number of times is called _____ repetition.

d) When it is not known in advance how many times a set of statements will be repeated, a _____ value can be used to terminate the repetition.

4.2 Write four different Java statements that each add 1 to integer variable **x**.

4.3 Write Java statements to accomplish each of the following tasks:

a) Assign the sum of **x** and **y** to **z**, and increment the value of **x** by 1 after the calculation. Use only one statement.

b) Test if the value of the variable **count** is greater than 10. If it is, print **"Count is greater than 10"**.

c) Decrement the variable **x** by 1, and then subtract it from the variable **total**. Use only one statement.

d) Calculate the remainder after **q** is divided by **divisor**, and assign the result to **q**. Write this statement in two different ways.

4.4 Write a Java statement to accomplish each of the following tasks:

a) Declare variables **sum** and **x** to be of type **int**.

b) Assign **1** to variable **x**.

c) Assign **0** to variable **sum**.

d) Add variable **x** to variable **sum**, and assign the result to variable **sum**.

e) Print **"The sum is: "**, followed by the value of variable **sum**.

4.5 Combine the statements that you wrote in Exercise 4.4 into a Java application that calculates and prints the sum of the integers from 1 to 10. Use the **while** structure to loop through the calculation and increment statements. The loop should terminate when the value of **x** becomes 11.

4.6 Determine the value of each variable after the calculation is performed. Assume that when each statement begins executing, all variables have the integer value 5.

a)
```
product *= x++;
```

b)
```
quotient /= ++x;
```

4.7 Identify and correct the errors in each of the following sets of code:

a)
```
while ( c <= 5 ) {
   product *= c;
   ++c;
```

b)
```
if ( gender == 1 )
   System.out.println( "Woman" );
else;
   System.out.println( "Man" );
```

4.8 What is wrong with the following **while** repetition structure?

```
while ( z >= 0 )
   sum += z;
```

ANSWERS TO SELF-REVIEW EXERCISES

4.1 a) sequence, selection, repetition. b) **if/else**. c) counter-controlled, or definite. d) Sentinel, signal, flag or dummy.

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4.2
```
x = x + 1;
x += 1;
++x;
x++;
```

4.3 a)
```
z = x++ + y;
```
b)
```
if ( count > 10 )
   System.out.println( "Count is greater than 10" );
```
c)
```
total -= --x;
```
d)
```
q %= divisor;
q = q % divisor;
```

4.4 a)
```
int sum, x;
```
b)
```
x = 1;
```
c)
```
sum = 0;
```
d)
```
sum += x;
```
or
```
sum = sum + x;
```
e)
```
System.out.println( "The sum is: " + sum );
```

4.5 The program is as follows:

```
1  // Calculate the sum of the integers from 1 to 10
2  public class Calculate {
3     public static void main( String args[] )
4     {
5        int sum, x;
6
7        x = 1;
8        sum = 0;
9
10       while ( x <= 10 ) {
11          sum += x;
12          ++x;
13       }
14
15       System.out.println( "The sum is: " + sum );
16    }
17 }
```

4.6 a) **product = 25**, **x = 6**

b) **quotient = 0**, **x = 6**

4.7 a) Error: Missing the closing right brace of the **while** structure's body.
Correction: Add a closing right brace after the statement **++c;**.

b) Error: Semicolon after **else** results in a logic error. The second output statement will always be executed.
Correction: Remove the semicolon after **else**.

4.8 The value of the variable **z** is never changed in the **while** structure. Therefore, if the loop-continuation condition **(z >= 0)** is true, an infinite loop is created. To prevent an infinite loop from occurring, **z** must be decremented so that it eventually becomes less than 0.

EXERCISES

4.9 Identify and correct the errors in each of the following sets of code. [*Note*: There may be more than one error in each piece of code]:

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a)
```
if ( age >= 65 );
   System.out.println( "Age greater than or equal to 65" );
else
   System.out.println( "Age is less than 65 )";
```
b)
```
int x = 1, total;
while ( x <= 10 ) {
   total += x;
   ++x;
}
```
c)
```
While ( x <= 100 )
   total += x;
   ++x;
```
d)
```
while ( y > 0 ) {
   System.out.println( y );
   ++y;
```

4.10 What does the following program print?

```
1  public class Mystery {
2
3     public static void main( String args[] )
4     {
5        int y, x = 1, total = 0;
6
7        while ( x <= 10 ) {
8           y = x * x;
9           System.out.println( y );
10          total += y;
11          ++x;
12       }
13
14       System.out.println( "Total is " + total );
15    }
16 }
```

For Exercise 4.11 through Exercise 4.14, perform each of the following steps:

a) Read the problem statement.
b) Formulate the algorithm using pseudocode and top-down, stepwise refinement.
c) Write a Java program.
d) Test, debug and execute the Java program.
e) Process three complete sets of data.

4.11 Drivers are concerned with the mileage obtained by their automobiles. One driver has kept track of several tankfuls of gasoline by recording miles driven and gallons used for each tankful. Develop a Java application that will input the miles driven and gallons used (both as integers) for each tankful. The program should calculate and display the miles per gallon obtained for each tankful and print the combined miles per gallon obtained for all tankfuls up to this point. All averaging calculations should produce floating-point results. Use input dialogs to obtain the data from the user.

4.12 Develop a Java application that will determine if a department-store customer has exceeded the credit limit on a charge account. For each customer, the following facts are available:

a) account number,
b) balance at the beginning of the month,

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c) total of all items charged by the customer this month,
d) total of all credits applied to the customer's account this month, and
e) allowed credit limit.

The program should input each of these facts from input dialogs as integers, calculate the new balance (= *beginning balance* + *charges* – *credits*), display the new balance and determine if the new balance exceeds the customer's credit limit. For those customers whose credit limit is exceeded, the program should display the message "Credit limit exceeded."

4.13 A large company pays its salespeople on a commission basis. The salespeople receive $200 per week, plus 9% of their gross sales for that week. For example, a salesperson who sells $5000 worth of merchandise in a week receives $200 plus 9% of $5000, or a total of $650. You have been supplied with a list of items sold by each salesperson. The values of these items are as follows:

```
Item   Value
1      239.99
2      129.75
3       99.95
4      350.89
```

Develop a Java application that inputs one salesperson's items sold for last week and calculates and displays that salesperson's earnings. There is no limit to the number of items that can be sold by a salesperson.

4.14 Develop a Java application that will determine the gross pay for each of three employees. The company pays "straight time" for the first 40 hours worked by each employee and pays "time and a half" for all hours worked in excess of 40 hours. You are given a list of the employees of the company, the number of hours each employee worked last week and the hourly rate of each employee. Your program should input this information for each employee and should determine and display the employee's gross pay. Use input dialogs to input the data.

4.15 The process of finding the largest value (i.e., the maximum of a group of values) is used frequently in computer applications. For example, a program that determines the winner of a sales contest would input the number of units sold by each salesperson. The salesperson who sells the most units wins the contest. Write a pseudocode program and then a Java application that inputs a series of 10 single-digit numbers as characters and determines and prints the largest of the numbers. *Hint*: Your program should use the following three variables:

a) **`counter`**: A counter to count to 10 (i.e., to keep track of how many numbers have been input and to determine when all 10 numbers have been processed);
b) **`number`**: The current digit input to the program;
c) **`largest`**: The largest number found so far.

4.16 Write a Java application that uses looping to print the following table of values:

```
N       10*N    100*N   1000*N

1       10      100     1000
2       20      200     2000
3       30      300     3000
4       40      400     4000
5       50      500     5000
```

4.17 Using an approach similar to that for Exercise 4.15, find the *two* largest values of the 10 digits entered. [*Note*: You may input each number only once.]

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4.18 Modify the program in Fig. 4.11 to validate its inputs. For any input, if the value entered is other than 1 or 2, keep looping until the user enters a correct value.

4.19 What does the following program print?

```
1  public class Mystery2 {
2
3     public static void main( String args[] )
4     {
5        int count = 1;
6
7        while ( count <= 10 ) {
8           System.out.println(
9              count % 2 == 1 ? "*****" : "++++++++" );
10          ++count;
11       }
12    }
13 }
```

4.20 What does the following program print?

```
1  public class Mystery3 {
2
3     public static void main( String args[] )
4     {
5        int row = 10, column;
6
7        while ( row >= 1 ) {
8           column = 1;
9
10          while ( column <= 10 ) {
11             System.out.print( row % 2 == 1 ? "<" : ">" );
12             ++column;
13          }
14
15          --row;
16          System.out.println();
17       }
18    }
19 }
```

4.21 *(Dangling-Else Problem)* Determine the output for each of the given sets of code when **x** is **9** and **y** is **11** and when **x** is **11** and **y** is **9**. Note that the compiler ignores the indentation in a Java program. Also, the Java compiler always associates an **else** with the previous **if** unless told to do otherwise by the placement of braces (**{}**). On first glance, the programmer may not be sure which **if** an **else** matches; this situation is referred to as the "dangling-else problem." We have eliminated the indentation from the following code to make the problem more challenging. [*Hint*: Apply indentation conventions you have learned.]

a)
```
if ( x < 10 )
if ( y > 10 )
System.out.println( "******" );
else
System.out.println( "#####" );
System.out.println( "$$$$$" );
```

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b)
```
if ( x < 10 ) {
if ( y > 10 )
System.out.println( "******" );
}
else {
System.out.println( "#####" );
System.out.println( "$$$$$" );
}
```

4.22 *(Another Dangling-Else Problem)* Modify the given code to produce the output shown in each part of the problem. Use proper indentation techniques. You may not make any changes other than inserting braces and changing the indentation of the code. The compiler ignores indentation in a Java program. We have eliminated the indentation from the given code to make the problem more challenging. [*Note*: It is possible that no modification is necessary for some of the parts.]

```
if ( y == 8 )
if ( x == 5 )
System.out.println( "@@@@@" );
else
System.out.println( "#####" );
System.out.println( "$$$$$" );
System.out.println( "&&&&&" );
```

a) Assuming that **x = 5** and **y = 8**, the following output is produced:

```
@@@@@
$$$$$
&&&&&
```

b) Assuming that **x = 5** and **y = 8**, the following output is produced:

```
@@@@@
```

c) Assuming that **x = 5** and **y = 8**, the following output is produced:

```
@@@@@
&&&&&
```

d) Assuming that **x = 5** and **y = 7**, the following output is produced [*Note*: The last three output statements after the **else** are all part of a block]:]

```
#####
$$$$$
&&&&&
```

4.23 Write an applet that reads in the size of the side of a square and displays a hollow square of that size out of asterisks, by using the **drawString** method inside your applet's **paint** method.

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Use an input dialog to read the size from the user. Your program should work for squares of all lengths of side between 1 and 20.

4.24 A palindrome is a number or a text phrase that reads the same backward as forward. For example, each of the following five-digit integers are palindromes: 12321, 55555, 45554 and 11611. Write an application that reads in a five-digit integer and determines whether or not it is a palindrome. If the number is not five digits long, display an error message dialog indicating the problem to the user. When the user dismisses the error dialog, allow the user to enter a new value.

4.25 Write an application that inputs an integer containing only 0s and 1s (i.e., a "binary" integer) and prints its decimal equivalent. [*Hint*: Use the modulus and division operators to pick off the "binary number's" digits one at a time, from right to left. Just as in the decimal number system, where the rightmost digit has a positional value of 1 and the next digit to the left has a positional value of 10, then 100, then 1000, etc., in the binary number system the rightmost digit has a positional value of 1, the next digit to the left has a positional value of 2, then 4, then 8, etc. Thus, the decimal number 234 can be interpreted as 4 * 1 + 3 * 10 + 2 * 100. The decimal equivalent of binary 1101 is 1 * 1 + 0 * 2 + 1 * 4 + 1 * 8, or 1 + 0 + 4 + 8 or, 13.]

4.26 Write an application that displays the following checkerboard pattern:

```
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
* * * * * * * *
 * * * * * * * *
```

Your program may use only three output statements, one of the form

```
System.out.print( "* " );
```

one of the form

```
System.out.print( " " );
```

and one of the form

```
System.out.println();
```

Note that the preceding statement indicates that the program should output a single newline character to drop to the next line of the output. [*Hint*: Repetition structures are required in this exercise.]

4.27 Write an application that keeps displaying in the command window the multiples of the integer 2, namely 2, 4, 8, 16, 32, 64, etc. Your loop should not terminate (i.e., you should create an infinite loop). What happens when you run this program?

4.28 What is wrong with the following statement? Provide the correct statement to add one to the sum of **x** and **y**.

```
System.out.println( ++(x + y) );
```

4.29 Write an application that reads three nonzero values entered by the user in input dialogs and determines and prints if they could represent the sides of a triangle.

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4.30 Write an application that reads three nonzero integers and determines and prints if they could represent the sides of a right triangle.

4.31 A company wants to transmit data over the telephone, but it is concerned that its phones may be tapped. All of its data are transmitted as four-digit integers. It has asked you to write a program that will encrypt its data so that the data may be transmitted more securely. Your application should read a four-digit integer entered by the user in an input dialog and encrypt it as follows: Replace each digit by *(the sum of that digit plus 7) modulus 10*. Then swap the first digit with the third, and swap the second digit with the fourth. Then print the encrypted integer. Write a separate application that inputs an encrypted four-digit integer and decrypts it to form the original number.

4.32 The factorial of a nonnegative integer n is written as $n!$ (pronounced "n factorial") and is defined as follows:

$n! = n \cdot (n - 1) \cdot (n - 2) \cdot \ldots \cdot 1$ (for values of n greater than or equal to 1)

and

$n! = 1$ (for $n = 0$).

For example, $5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$, which is 120.

a) Write an application that reads a nonnegative integer from an input dialog and computes and prints its factorial.

b) Write an application that estimates the value of the mathematical constant e by using the formula

$$e = 1 + \frac{1}{1!} + \frac{1}{2!} + \frac{1}{3!} + \ldots$$

c) Write an application that computes the value of e^x by using the formula:

$$e^x = 1 + \frac{x}{1!} + \frac{x^2}{2!} + \frac{x^3}{3!} + \ldots$$

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Control Structures: Part 2

Objectives

- To be able to use the **`for`** and **`do/while`** repetition structures to execute statements in a program repeatedly.
- To understand multiple selection using the **`switch`** selection structure.
- To be able to use the **`break`** and **`continue`** program control statements.
- To be able to use the logical operators.

Who can control his fate?
William Shakespeare, *Othello*

The used key is always bright.
Benjamin Franklin

Man is a tool-making animal.
Benjamin Franklin

Intelligence … is the faculty of making artificial objects, especially tools to make tools.
Henri Bergson

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Outline

5.1 Introduction
5.2 Essentials of Counter-Controlled Repetition
5.3 The `for` Repetition Structure
5.4 Examples Using the `for` Structure
5.5 The `switch` Multiple-Selection Structure
5.6 The `do/while` Repetition Structure
5.7 Statements `break` and `continue`
5.8 Labeled `break` and `continue` Statements
5.9 Logical Operators
5.10 Structured Programming Summary
5.11 (Optional Case Study) Thinking About Objects: Identifying Objects' States and Activities

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

5.1 Introduction

Chapter 4 began our introduction to the types of building blocks that are available for problem solving and used those building blocks to employ proven program construction principles. In this chapter, we continue our presentation of the theory and principles of structured programming by introducing Java's remaining control structures. As in Chapter 4, the Java techniques you learn here are applicable to most high-level languages. When we begin our formal treatment of object-based programming in Java in Chapter 8, we will see that the control structures we study in this chapter and Chapter 4 are helpful in building and manipulating objects.

5.2 Essentials of Counter-Controlled Repetition

Counter-controlled repetition requires the following:

1. the *name* of a control variable (or loop counter),
2. the *initial value* of the control variable,
3. the amount of *increment* (or *decrement*) by which the control variable is modified each time through the loop (also known as *each iteration of the loop*), and
4. the condition that tests for the *final value* of the control variable (i.e., whether looping should continue).

To see the four elements of counter-controlled repetition, consider the applet shown in Fig. 5.1, which draws 10 lines from the applet's **`paint`** method. Remember that an applet requires a separate HTML document to load the applet into the **`appletviewer`** or a browser. For the purpose of this applet, the **`<applet>`** tag specifies a width of **`275`** pixels and a height of **`110`** pixels.

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```
1  // Fig. 5.1: WhileCounter.java
2  // Counter-controlled repetition
3
4  // Java core packages
5  import java.awt.Graphics;
6
7  // Java extension packages
8  import javax.swing.JApplet;
9
10 public class WhileCounter extends JApplet {
11
12    // draw lines on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
17
18       int counter = 1;              // initialization
19
20       while ( counter <= 10 ) {     // repetition condition
21          g.drawLine( 10, 10, 250, counter * 10 );
22          ++counter;                 // increment
23
24       }  // end while structure
25
26    }  // end method paint
27
28 }  // end class WhileCounter
```

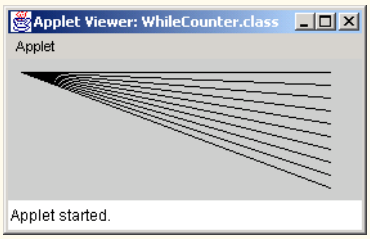

Fig. 5.1 Counter-controlled repetition.

The applet's **paint** method (that the applet container calls when it executes the applet) operates as follows: The declaration on line 18 *names* the control variable (**counter**), declares it to be an integer, reserves space for it in memory and sets it to an *initial value* of **1**. Declarations that include initialization are, in effect, executable statements. The declaration and initialization of **counter** could also have been accomplished with the declaration and statement

```
int counter;  // declare counter
counter = 1;  // initialize counter to 1
```

The declaration is not executable, but the assignment statement is. We use both methods of initializing variables throughout this book.

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Line 21 in the **while** structure uses **Graphics** reference **g**, which refers to the applet's **Graphics** object, to send the **drawLine** message to the **Graphics** object, asking it to draw a line. Remember that "sending a message to an object" actually means calling a method to perform a task. One of the **Graphics** object's many services is to draw lines. In previous chapters, we also saw that the **Graphics** object's other services include drawing rectangles, strings and ovals. **Graphics** method **drawLine** requires four arguments, representing the line's first *x*-coordinate, first *y*-coordinate, second *x*-coordinate and second *y*-coordinate. In this example, the second *y*-coordinate changes value during each iteration of the loop with the calculation **counter * 10**. This change causes the second point (the end point of the line) in each call to **drawLine** to move 10 pixels down the applet's display area.

Line 22 in the **while** structure *increments* the control variable by 1 for each iteration of the loop. The loop-continuation condition in the **while** structure tests whether the value of the control variable is less than or equal to **10** (the *final value* for which the condition is **true**). Note that the program performs the body of this **while** structure even when the control variable is **10**. The loop terminates when the control variable exceeds **10** (i.e., **counter** becomes **11**).

The program in Fig. 5.1 can be made more concise by initializing **counter** to **0** and preincrementing **counter** in the **while** structure condition as follows:

```
while ( ++counter <= 10 )      // repetition condition
   g.drawLine( 10, 10, 250, counter * 10 );
```

This code saves a statement (and eliminates the need for braces around the loop's body), because the **while** condition performs the increment before testing the condition. (Remember that the precedence of **++** is higher than that of **<=**.) Coding in such a condensed fashion takes practice.

Good Programming Practice 5.1

Programs should control counting loops with integer values.

Common Programming Error 5.1

Because floating-point values may be approximate, controlling the counting of loops with floating-point variables may result in imprecise counter values and inaccurate tests for termination.

Good Programming Practice 5.2

Indent the statements in the body of each control structure.

Good Programming Practice 5.3

Put a blank line before and after each major control structure to make it stand out in the program.

Good Programming Practice 5.4

Too many levels of nesting can make a program difficult to understand. As a general rule, try to avoid using more than three levels of nesting.

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Good Programming Practice 5.5

Vertical spacing above and below control structures, and indentation of the bodies of control structures within the control structures' headers, gives programs a two-dimensional appearance that enhances readability.

5.3 The `for` Repetition Structure

The **`for`** repetition structure handles all of the details of counter-controlled repetition. To illustrate the power of the **`for`** structure, let us rewrite the applet of Fig. 5.1. The result is shown in Fig. 5.2. Remember that this program requires a separate HTML document to load the applet into the **`appletviewer`**. For the purpose of this applet, the **`<applet>`** tag specifies a width of **`275`** pixels and a height of **`110`** pixels.

```
1  // Fig. 5.2: ForCounter.java
2  // Counter-controlled repetition with the for structure
3
4  // Java core packages
5  import java.awt.Graphics;
6
7  // Java extension packages
8  import javax.swing.JApplet;
9
10 public class ForCounter extends JApplet {
11
12    // draw lines on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
17
18       // Initialization, repetition condition and incrementing
19       // are all included in the for structure header.
20       for ( int counter = 1; counter <= 10; counter++ )
21          g.drawLine( 10, 10, 250, counter * 10 );
22
23    }  // end method paint
24
25 }  // end class ForCounter
```

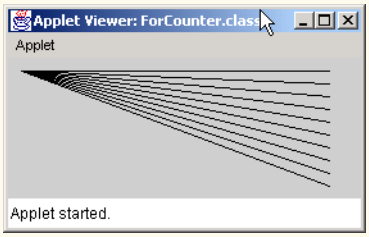

Fig. 5.2 Counter-controlled repetition with the **`for`** structure.

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The applet's **paint** method operates as follows: When the **for** structure (lines 20–21) begins executing, the control variable **counter** is initialized to **1**. (The first two elements of counter-controlled repetition and the *name* of the control variable and its *initial value*.) Next, the program checks the loop-continuation condition, **counter <= 10**. The condition contains the *final value* (**10**) of the control variable. Because the initial value of **counter** is **1**, the condition is satisfied (**true**), so the body statement (line 21) draws a line. After executing the body of the loop, the program increments variable **counter** in the expression **counter++**. Then, the program performs the loop-continuation test again to determine whether the program should continue with the next iteration of the loop or whether it should terminate the loop. At this point, the control variable value is **2**, so the condition is true (i.e., the final value is not exceeded), and thus the program performs the body statement again (i.e., the next iteration of the loop). This process continues until the **counter**'s value becomes **11**, causing the loop-continuation test to fail and repetition to terminate. Then, the program performs the first statement after the **for** structure. (In this case, method **paint** terminates, because the program reaches the end of **paint**.)

Notice that Fig. 5.2 uses the loop-continuation condition **counter <= 10**. If the programmer incorrectly specified **counter < 10** as the condition, the loop would be executed only nine times. This mistake is a common logic error called an *off-by-one error*.

Common Programming Error 5.2

*Using an incorrect relational operator or using an incorrect final value of a loop counter in the condition of a **while**, **for** or **do/while** structure can cause an off-by-one error.*

Good Programming Practice 5.6

*Using the final value in the condition of a **while** or **for** structure and using the **<=** relational operator will help avoid off-by-one errors. For a loop that prints the values 1 to 10, the loop-continuation condition should be **counter <= 10** rather than **counter < 10** (which causes an off-by-one error) or **counter < 11** (which is correct). Many programmers prefer so-called zero-based counting, in which to count 10 times, **counter** would be initialized to zero and the loop-continuation test would be **counter < 10**.*

Figure 5.3 takes a closer look at the **for** structure of Fig. 5.2. The **for** structure's first line (including the keyword **for** and everything in parentheses after **for**) is sometimes called the ***for** structure header*. Notice that the **for** structure "does it all": It specifies each of the items needed for counter-controlled repetition with a control variable. If there is more than one statement in the body of the **for** structures, braces (**{** and **}**) are required to define the body of the loop.

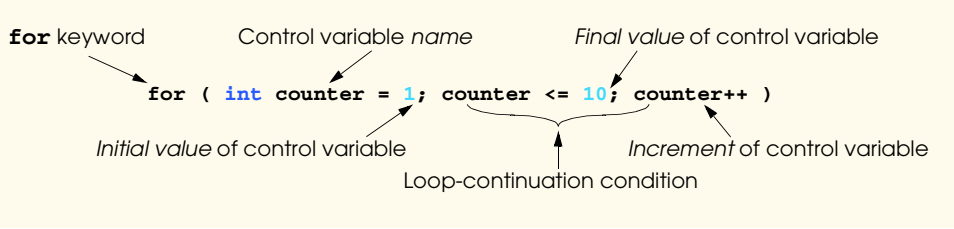

Fig. 5.3 Components of a typical **for** structure header.

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The general format of the **for** structure is

```
for ( expression1; expression2; expression3 )
    statement
```

where *expression1* names the loop's control variable and provides its initial value, *expression2* is the loop-continuation condition (containing the control variable's final value) and *expression3* modifies the value of the control variable, so that the loop-continuation condition eventually becomes **false**. In most cases, the **for** structure can be represented with an equivalent **while** structure, with *expression1*, *expression2* and *expression3* placed as follows:

```
expression1;

while ( expression2 ) {
    statement
    expression3;
}
```

In Section 5.7, we show a case in which a **for** structure cannot be represented with an equivalent **while** structure.

If *expression1* (the initialization section) declares the control variable inside the parentheses of the header of the **for** structure (i.e., the control variable's type is specified before the name of the variable), the control variable can be used only in the **for** structure. This restricted use of the name of the control variable is known as the variable's *scope*. The scope of a variable defines where the program can use the variable. For example, we mentioned previously that a program can use a local variable only in the method that declares the variable. Scope is discussed in detail in Chapter 6, "Methods."

Common Programming Error 5.3

When the control variable of a **for** *structure is initially defined in the initialization section of the header of the* **for** *structure, using the control variable after the body of the structure is a syntax error.*

Sometimes, *expression1* and *expression3* in a **for** structure are comma-separated lists of expressions that enable the programmer to use multiple initialization expressions and/or multiple increment expressions. For example, there may be several control variables in a single **for** structure that must be initialized and incremented.

Good Programming Practice 5.7

Place only expressions involving the control variables in the initialization and increment sections of a **for** *structure. Manipulations of other variables should appear either before the loop (if they execute only once, like initialization statements) or in the body of the loop (if they execute once per iteration of the loop, like incrementing or decrementing statements).*

The three expressions in the **for** structure are optional. If *expression2* is omitted, Java assumes that the loop-continuation condition is **true**, thus creating an infinite loop. One might omit *expression1* if the program initializes the control variable before the loop. One might omit *expression3* if the program calculates the increment with statements in the loop's body or if the loop does not require an increment. The increment expression in the **for** structure acts as a stand-alone statement at the end of the body of the **for** structure, so the expressions

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```
counter = counter + 1
counter += 1
++counter
counter++
```

are equivalent in the increment portion of the **for** structure. Many programmers prefer the form **counter++**, because a **for** structure increments its control variable after the body of the loop executes and placing **++** after the variable name increments the variable after the program uses its value. Therefore, the postincrementing form seems more natural. Preincrementing and postincrementing *have the same effect in the increment expression*, because the increment does not appear in a larger expression. The two semicolons in the **for** structure are required.

Common Programming Error 5.4

*Using commas instead of the two required semicolons in a **for** header is a syntax error.*

Common Programming Error 5.5

*Placing a semicolon immediately to the right of the right parenthesis of a **for** header makes the body of that **for** structure an empty statement. This is normally a logic error.*

The initialization, loop-continuation condition and increment portions of a **for** structure can contain arithmetic expressions. For example, assume that **x = 2** and **y = 10**. If **x** and **y** are not modified in the body of the loop, the statement

```
for ( int j = x; j <= 4 * x * y; j += y / x )
```

is equivalent to the statement

```
for ( int j = 2; j <= 80; j += 5 )
```

The increment of a **for** structure may also be negative, in which case it is really a decrement, and the loop actually counts downward.

If the loop-continuation condition is initially **false**, the program does not perform the body of the **for** structure. Instead, execution proceeds with the statement following the **for** structure.

Programs frequently display the control variable value or use it in calculations in loop body. However, this use is not required. It is common to use the control variable for controlling repetition while never mentioning it in the body of the **for** structure.

Testing and Debugging Tip 5.1

*Although the value of the control variable can be changed in the body of a **for** loop, avoid doing so, because this practice can lead to subtle errors.*

We flowchart the **for** structure much as we do the **while** structure. For example, the flowchart of the **for** statement

```
for ( int counter = 1; counter <= 10; counter++ )
   g.drawLine( 10, 10, 250, counter * 10 );
```

is shown in Fig. 5.4. This flowchart makes it clear that the initialization occurs only once and that the increment occurs each time *after* the program performs the body statement.

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Note that, besides small circles and arrows, the flowchart contains only rectangle symbols and a diamond symbol. The programmer fills the rectangles and diamonds with actions and decisions appropriate to the algorithm.

5.4 Examples Using the `for` Structure

The examples given next show methods of varying the control variable in a **`for`** structure. In each case, we write the appropriate **`for`** structure header. Note the change in the relational operator for loops that decrement the control variable.

a) Vary the control variable from **`1`** to **`100`** in increments of **`1`**.

```
for ( int i = 1; i <= 100; i++ )
```

b) Vary the control variable from **`100`** to **`1`** in increments of **`-1`** (i.e., decrements of **`1`**).

```
for ( int i = 100; i >= 1; i-- )
```

c) Vary the control variable from **`7`** to **`77`** in steps of **`7`**.

```
for ( int i = 7; i <= 77; i += 7 )
```

d) Vary the control variable from **`20`** to **`2`** in steps of **`-2`**.

```
for ( int i = 20; i >= 2; i -= 2 )
```

e) Vary the control variable over the following sequence of values: **`2`**, **`5`**, **`8`**, **`11`**, **`14`**, **`17`**, **`20`**.

```
for ( int j = 2; j <= 20; j += 3 )
```

f) Vary the control variable over the following sequence of values: **`99`**, **`88`**, **`77`**, **`66`**, **`55`**, **`44`**, **`33`**, **`22`**, **`11`**, **`0`**.

```
for ( int j = 99; j >= 0; j -= 11 )
```

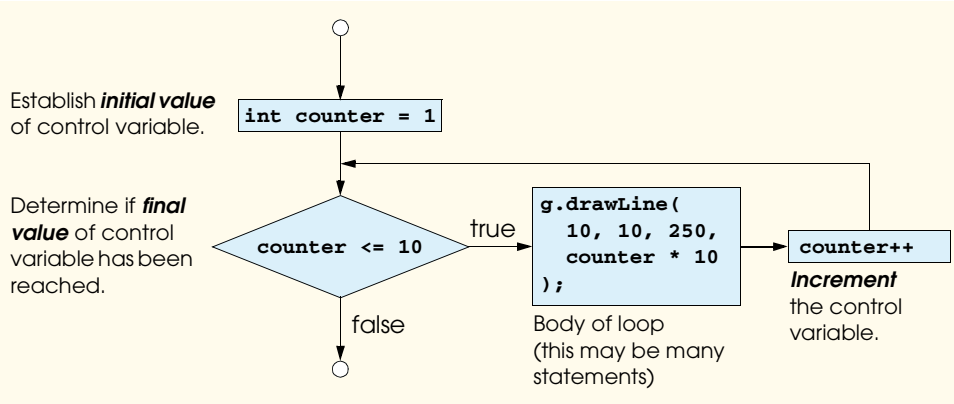

Fig. 5.4 Flowcharting a typical **`for`** repetition structure.

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Common Programming Error 5.6

Not using the proper relational operator in the loop-continuation condition of a loop that counts downward (such as using **`i <= 1`** *in a loop counting down to 1) is usually a logic error and will yield incorrect results when the program runs.*

The next two sample programs demonstrate simple applications of the **`for`** repetition structure. The application in Fig. 5.5 uses the **`for`** structure to sum all the even integers from **`2`** to **`100`**. Remember that the **`java`** interpreter is used to execute an application from the command window.

Note that the body of the **`for`** structure in Fig. 5.5 could actually be merged into the rightmost portion of the **`for`** header by using a comma as follows:

```
for ( int number = 2;
      number <= 100;
      sum += number, number += 2 )
   ;  // empty statement
```

```
1  // Fig. 5.5: Sum.java
2  // Counter-controlled repetition with the for structure
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class Sum {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int sum = 0;
13
14       // sum even integers from 2 through 100
15       for ( int number = 2; number <= 100; number += 2 )
16          sum += number;
17
18       // display results
19       JOptionPane.showMessageDialog( null, "The sum is " + sum,
20          "Sum Even Integers from 2 to 100",
21          JOptionPane.INFORMATION_MESSAGE );
22
23       System.exit( 0 );   // terminate the application
24
25    }  // end method main
26
27 }  // end class Sum
```

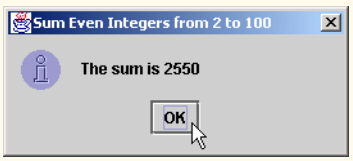

Fig. 5.5 Summation with the **`for`** structure.

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Similarly, the initialization **sum = 0** could be merged into the initialization section of the **for** structure.

Good Programming Practice 5.8

Although statements preceding a **for** *structure and statements in the body of a* **for** *structure can often be merged into the header of the* **for** *structure, avoid doing so, because it makes the program more difficult to read.*

Good Programming Practice 5.9

Limit the size of control structure headers to a single line. if possible.

The next example uses the **for** structure to compute compound interest. Consider the following problem:

> *A person invests $1000.00 in a savings account yielding 5% interest. Assuming that all interest is left on deposit, calculate and print the amount of money in the account at the end of each year for 10 years. Use the following formula to determine the amounts:*
>
> $a = p\,(1 + r)^n$
>
> *where*
>
> *p* is the original amount invested (i.e., the principal)
> *r* is the annual interest rate
> *n* is the number of years
> *a* is the amount on deposit at the end of the *n*th year.

This problem involves a loop that performs the indicated calculation for each of the 10 years the money remains on deposit. The solution is the application shown in Fig. 5.6.

```
1  // Fig. 5.6: Interest.java
2  // Calculating compound interest
3
4  // Java core packages
5  import java.text.NumberFormat;
6  import java.util.Locale;
7
8  // Java extension packages
9  import javax.swing.JOptionPane;
10 import javax.swing.JTextArea;
11
12 public class Interest {
13
14    // main method begins execution of Java application
15    public static void main( String args[] )
16    {
17       double amount, principal = 1000.0, rate = 0.05;
18
19       // create DecimalFormat to format floating-point numbers
20       // with two digits to the right of the decimal point
21       NumberFormat moneyFormat =
22          NumberFormat.getCurrencyInstance( Locale.US );
23
```

Fig. 5.6 Calculating compound interest with the **for** structure (part 1 of 2).

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```
24         // create JTextArea to display output
25         JTextArea outputTextArea = new JTextArea();
26
27         // set first line of text in outputTextArea
28         outputTextArea.setText( "Year\tAmount on deposit\n" );
29
30         // calculate amount on deposit for each of ten years
31         for ( int year = 1; year <= 10; year++ ) {
32
33            // calculate new amount for specified year
34            amount = principal * Math.pow( 1.0 + rate, year );
35
36            // append one line of text to outputTextArea
37            outputTextArea.append( year + "\t" +
38               moneyFormat.format( amount ) + "\n" );
39
40         }  // end for structure
41
42         // display results
43         JOptionPane.showMessageDialog( null, outputTextArea,
44            "Compound Interest", JOptionPane.INFORMATION_MESSAGE );
45
46         System.exit( 0 );  // terminate the application
47
48      }  // end method main
49
50   }  // end class Interest
```

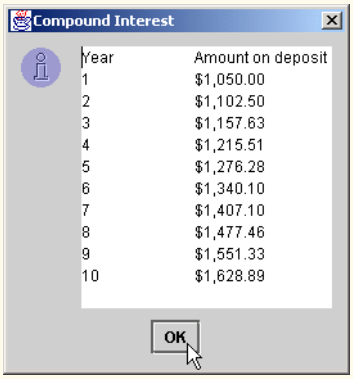

Fig. 5.6 Calculating compound interest with the **for** structure (part 2 of 2).

Line 17 in method **main** declares three **double** variables and initializes two of them—**principal** to **1000.0** and **rate** to **.05**. Java treats floating-point constants, like **1000.0** and **.05** in Fig. 5.6, as type **double**. Similarly, Java treats whole number constants, like **7** and **-22**, as type **int**. Lines 21–22 declare ***NumberFormat*** reference **moneyFormat** and initialize it by calling **static** method ***getCurrencyInstance*** of class **NumberFormat**. This method returns a **NumberFormat** object that can format numeric values as currency (e.g., in the United States, currency values normally are preceded with a dollar sign, $). The argument to the method—**Locale.US**—indicates that

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the currency values should be displayed starting with a dollar sign ($), use a decimal point to separate dollars and cents and use a comma to delineate thousands (e.g., $1,234.56). Class **Locale** provides constants that can be used to customize this program to represent currency values for other countries, so that currency formats are displayed properly for each *locale* (i.e., each country's local-currency format). Class **NumberFormat** (imported at line 5) is located in package **java.text**, and class **Locale** (imported at line 6) is located in package ***java.util***.

Line 25 declares **JTextArea** reference **outputTextArea** and initializes it with a new object of class **JTextArea** (from package **javax.swing**). A **JTextArea** is a GUI component that can display many lines of text. The message dialog that displays the **JTextArea** determines the width and height of the **JTextArea**, based on the **String** it contains. We introduce this GUI component now because we will see many examples throughout the text in which the program outputs contain too many lines to display on the screen. This GUI component allows us to scroll through the lines of text so we can see all the program output. The methods for placing text in a **JTextArea** include ***setText*** and ***append***.

Line 28 uses **JTextArea** method **setText** to place a **String** in the **JTextArea** to which **outputTextArea** refers. Initially, a **JTextArea** contains an empty **String** (i.e., a **String** with no characters in it). The preceding statement replaces the empty **String** with one containing the column heads for our two columns of output—"**Year**" and "**Amount on Deposit**." The column heads are separated with a tab character (escape sequence **\t**). Also, the string contains the newline character (escape sequence **\n**), indicating that any additional text appended to the **JTextArea** should begin on the next line.

The **for** structure (lines 31–40) executes its body 10 times, varying control variable **year** from 1 to 10 in increments of 1. (Note that **year** represents n in the statement of the problem.) Java does not include an exponentiation operator. Instead, we use **static** method **pow** of class **Math** for this purpose. **Math.pow(x, y)** calculates the value of **x** raised to the **y**th power. Method **pow** takes two arguments of type **double** and returns a **double** value. Line 34 performs the calculation from the statement of the problem,

$$a = p\,(1 + r)^{n}$$

where a is **amount**, p is **principal**, r is **rate** and n is **year**.

Lines 37–38 **append** more text to the end of the **outputTextArea**. The text includes the current value of **year**, a tab character (to position to the second column), the result of the method call **moneyFormat.format(amount)**—which formats the **amount** as U. S. currency—and a newline character (to position the cursor in the **JTextArea** at the beginning of the next line).

Lines 43–44 display the results in a message dialog. Until now, the message displayed has always been a **String**. In this example, the second argument is **outputTextArea**—a GUI component. An interesting feature of class **JOptionPane** is that the message it displays with **showMessageDialog** can be a **String** or a GUI component, such as a **JTextArea**. In this example, the message dialog sizes itself to accommodate the **JTextArea**. We use this technique several times early in this chapter to display large text-based outputs. Later in this chapter, we demonstrate how to add a scrolling capability to the **JTextArea**, so the user can view a program's output that is too large to display in full on the screen.

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Notice that the variables **amount**, **principal** and **rate** are of type **double**. We did this for simplicity, because we are dealing with fractional parts of dollars and thus need a type that allows decimal points in its values. Unfortunately, this setting can cause trouble. Here is a simple explanation of what can go wrong when using **float** or **double** to represent dollar amounts (assuming that dollar amounts are displayed with two digits to the right of the decimal point): Two **double** dollar amounts stored in the machine could be 14.234 (which would normally be rounded to 14.23 for display purposes) and 18.673 (which would normally be rounded to 18.67 for display purposes). When these amounts are added, they produce the internal sum 32.907, which would normally be rounded to 32.91 for display purposes. Thus, your printout could appear as

```
  14.23
+ 18.67
-------
  32.91
```

but a person adding the individual numbers as printed would expect the sum to be 32.90. You have been warned!

Good Programming Practice 5.10

*Do not use variables of type **float** or **double** to perform precise monetary calculations. The imprecision of floating-point numbers can cause errors that will result in incorrect monetary values. In the exercises, we explore the use of integers to perform monetary calculations. [*Note*: Some third-party vendors provide for-sale class libraries that perform precise monetary calculations.]*

Note that the body of the **for** structure contains the calculation **1.0 + rate**, which appears as an argument to the **Math.pow** method. In fact, this calculation produces the same result each time through the loop, so repeating the calculation every iteration of the loop is wasteful.

Performance Tip 5.1

Avoid placing expressions whose values do not change inside loops. But even if you do, many of today's sophisticated optimizing compilers will place such expressions outside loops in the generated compiled code.

Performance Tip 5.2

Many compilers contain optimization features that improve the code that you write, but it is still better to write good code from the start.

5.5 The switch Multiple-Selection Structure

We have discussed the **if** single-selection structure and the **if/else** double-selection structure. Occasionally, an algorithm contains a series of decisions in which the algorithm tests a variable or expression separately for each of the constant integral values (i.e., values of types **byte**, **short**, **int** and **char**) the variable or expression may assume and takes different actions based on those values. Java provides the **switch** multiple-selection structure to handle such decision making. The applet of Fig. 5.7 demonstrates drawing lines, rectangles or ovals, based on an integer the user inputs via an input dialog.

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```
1  // Fig. 5.7: SwitchTest.java
2  // Drawing lines, rectangles or ovals based on user input.
3
4  // Java core packages
5  import java.awt.Graphics;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class SwitchTest extends JApplet {
11    int choice;   // user's choice of which shape to draw
12
13    // initialize applet by obtaining user's choice
14    public void init()
15    {
16       String input;  // user's input
17
18       // obtain user's choice
19       input = JOptionPane.showInputDialog(
20                   "Enter 1 to draw lines\n" +
21                   "Enter 2 to draw rectangles\n" +
22                   "Enter 3 to draw ovals\n" );
23
24       // convert user's input to an int
25       choice = Integer.parseInt( input );
26    }
27
28    // draw shapes on applet's background
29    public void paint( Graphics g )
30    {
31       // call inherited version of method paint
32       super.paint( g );
33
34       // loop 10 times, counting from 0 through 9
35       for ( int i = 0; i < 10; i++ ) {
36
37          // determine shape to draw based on user's choice
38          switch ( choice ) {
39
40             case 1:
41                g.drawLine( 10, 10, 250, 10 + i * 10 );
42                break;  // done processing case
43
44             case 2:
45                g.drawRect( 10 + i * 10, 10 + i * 10,
46                   50 + i * 10, 50 + i * 10 );
47                break;  // done processing case
48
49             case 3:
50                g.drawOval( 10 + i * 10, 10 + i * 10,
51                   50 + i * 10, 50 + i * 10 );
52                break;  // done processing case
53
```

Fig. 5.7 An example using **switch** (part 1 of 3).

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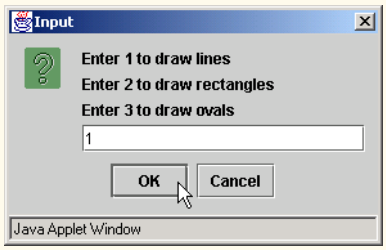
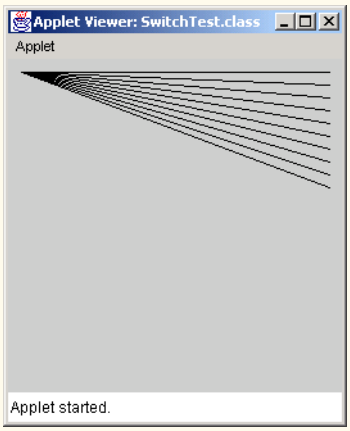
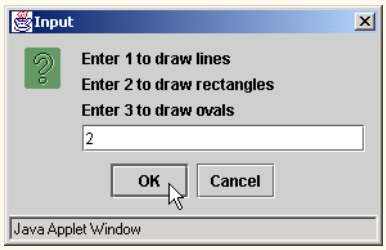
```
54                default:
55                   g.drawString( "Invalid value entered",
56                      10, 20 + i * 15 );
57
58             }  // end switch structure
59
60          }  // end for structure
61
62       }  // end paint method
63
64    }  // end class SwitchTest
```







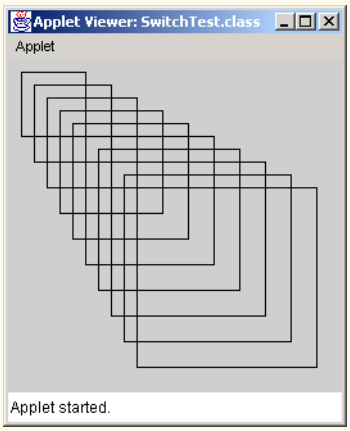


Fig. 5.7 An example using **switch** (part 2 of 3).

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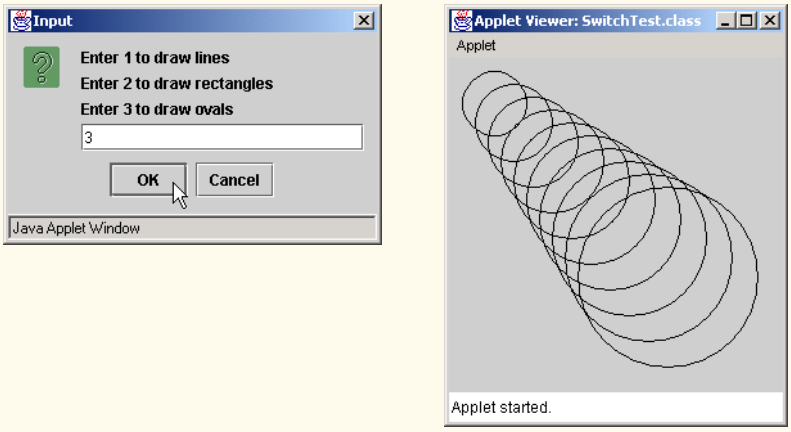

Fig. 5.7 An example using **switch** (part 3 of 3).

Line 11 in applet **SwitchTest** defines instance variable **choice** of type **int**. This variable stores the user's input that determines which type of shape to draw in **paint**.

Method **init** (lines 14–26) declares local variable **input** of type **String** in line 16. This variable stores the **String** the user types in the input dialog. Lines 19–22 display the input dialog with **static** method **JOptionPane.showInputDialog** and prompt the user to enter **1** to draw lines, **2** to draw rectangles or **3** to draw ovals. Line 25 converts input from a **String** to an **int** and assigns the result to **choice**.

Method **paint** (lines 29–62) contains a **for** structure (lines 35–60) that loops 10 times. In this example, the **for** structure's header, in line 35, uses zero-based counting. The values of **i** for the 10 iterations of the loop are 0, 1, 2, 3, 4, 5, 6, 7, 8 and 9, and the loop terminates when **i**'s value becomes 10. [*Note*: As you know, the applet container calls method **paint** after methods **init** and **start**. The applet container also calls method **paint** whenever the applet's screen area must be refreshed—e.g., after another window that covered the applet's area is moved to a different location on the screen.]

Nested in the **for** structure's body is a **switch** structure (lines 38–58) that draws shapes based on the integer value input by the user in method **init**. The **switch** structure consists of a series of ***case*** *labels* and an optional ***default*** *case*.

When the flow of control reaches the **switch** structure, the program evaluates the *controlling expression* (**choice**) in the parentheses following keyword **switch**. The program compares the value of the controlling expression (which must evaluate to an integral value of type **byte**, **char**, **short** or **int**) with each ***case*** *label*. Assume that the user entered the integer **2** as his or her choice. The program compares **2** with each **case** in the **switch**. If a match occurs (**case 2:**), the program executes the statements for that **case**. For the integer **2**, lines 44–47 draw a rectangle, using four arguments, representing the upper left *x*-coordinate, upper left *y*-coordinate, width and height of the rectangle, and the **switch** structure exits immediately with the **break** statement. Then, the program increments the counter variable in the **for** structure and reevaluates the loop-continuation condition to determine whether to perform another iteration of the loop.

The **break** statement causes program control to proceed with the first statement after the **switch** structure. (In this case, we reach the end of the **for** structure's body, so con-

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trol flows to the control variable's increment expression in the header of the **for** structure.) Without **break**, the **case**s in a **switch** statement would run together. Each time a match occurs in the structure, the statements for all the remaining **case**s will execute. (This feature is perfect for programming the iterative song "The Twelve Days of Christmas.") If no match occurs between the controlling expression's value and a **case** label, the **default** case executes, and the program draws an error message on the applet.

Each **case** can have multiple actions. The **switch** structure differs from other structures in that it does not require braces around multiple actions in each **case**. Figure 5.8 shows the general **switch** structure flowchart (using a **break** in each **case**). [*Note*: As an exercise, make a flowchart of the general **switch** structure without **break**s.]

The flowchart makes it clear that each **break** statement at the end of a **case** causes control to exit the **switch** structure immediately. The **break** statement is not required for the last **case** in the **switch** structure (or the **default** case, when it appears last), because the program continues with the next statement after the **switch**.

Again, note that, besides small circles and arrows, the flowchart contains only rectangle and diamond symbols. It is the programmer's responsibility to fill the rectangles and diamonds with actions and decisions appropriate to the algorithm. Although nested control structures are common, it is rare to find nested **switch** structures in a program.

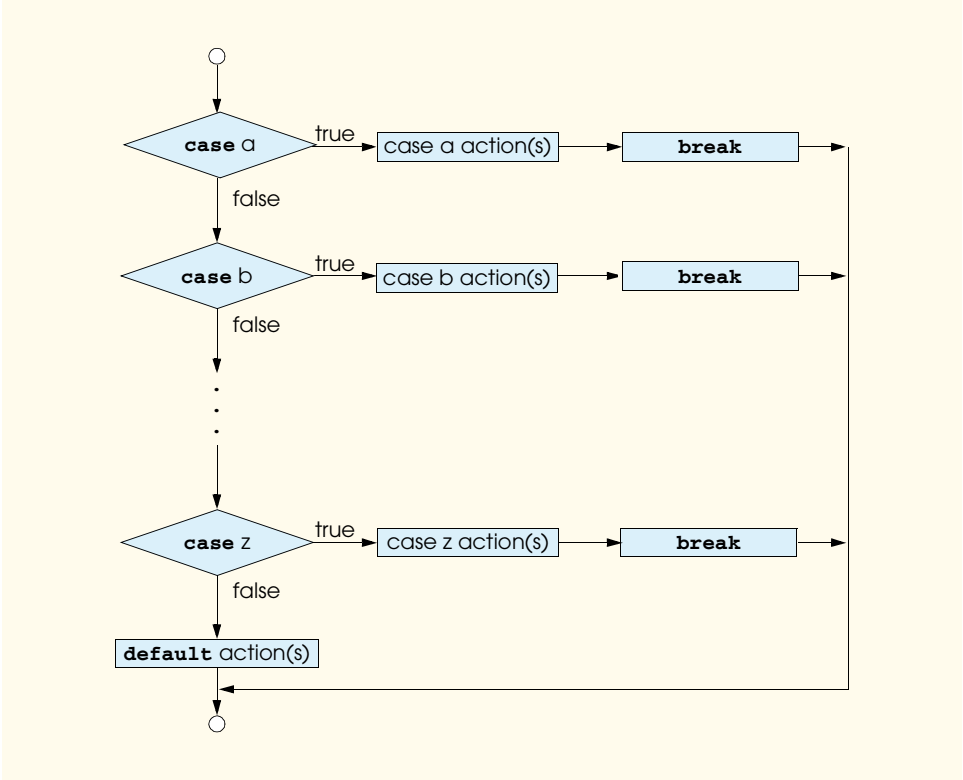

Fig. 5.8 The **switch** multiple-selection structure.

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Common Programming Error 5.7

Forgetting a **`break`** *statement when one is needed in a* **`switch`** *structure is a logic error.*

Good Programming Practice 5.11

Provide a **`default`** *case in* **`switch`** *statements. Cases not explicitly tested in a* **`switch`** *statement without a* **`default`** *case are ignored. Including a* **`default`** *case focuses the programmer on the need to process exceptional conditions. There are situations in which no* **`default`** *processing is needed.*

Good Programming Practice 5.12

Although the **`case`***s and the* **`default`** *case in a* **`switch`** *structure can occur in any order, it is considered a good programming practice to place the* **`default`** *clause last.*

Good Programming Practice 5.13

In a **`switch`** *structure, when the* **`default`** *clause is listed last, the* **`break`** *for that* **`case`** *statement is not required. Some programmers include this* **`break`** *for clarity and symmetry with other cases.*

Note that listing **`case`** labels together (such as **`case 1: case 2:`** with no statements between the cases) performs the same set of actions for each case.

When using the **`switch`** structure, remember that the expression after each **`case`** can be only a *constant integral expression* (i.e., any combination of character constants and integer constants that evaluates to a constant integer value). A character constant is represented as the specific character in single quotes, such as **`'A'`**. An integer constant is simply an integer value. The expression after each **`case`** also can be a *constant variable*—i.e., a variable that contains a value which does not change for the entire program. Such a variable is declared with keyword **`final`** (discussed in Chapter 6). When we discuss object-oriented programming in Chapter 9, we present a more elegant way to implement **`switch`** logic. We use a technique called *polymorphism* to create programs that are often clearer, easier to maintain and easier to extend than programs using **`switch`** logic.

5.6 The `do/while` Repetition Structure

The **`do/while`** repetition structure is similar to the **`while`** structure. In the **`while`** structure, the program tests the loop-continuation condition at the beginning of the loop, before performing the body of the loop. The **`do/while`** structure tests the loop-continuation condition *after* performing the body of the loop; therefore, *the loop body always executes at least once*. When a **`do/while`** structure terminates, execution continues with the statement after the **`while`** clause. Note that it is not necessary to use braces in the **`do/while`** structure if there is only one statement in the body. However, most programmers include the braces, to avoid confusion between the **`while`** and **`do/while`** structures. For example,

```
while ( condition )
```

normally is the first line of a **`while`** structure. A **`do/while`** structure with no braces around a single-statement body appears as

```
do
   statement
while ( condition );
```

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which can be confusing. Reader may misinterpret the last line—**while(** *condition* **);**—as a **while** structure containing an empty statement (the semicolon by itself). Thus, to avoid confusion, the **do/while** structure with one statement often is written as follows:

```
do {
   statement
} while ( condition );
```

Good Programming Practice 5.14

Some programmers always include braces in a ***do/while*** *structure, even if the braces are not necessary. This helps eliminate ambiguity between the* ***while*** *structure and the* ***do/while*** *structure containing only one statement.*

Common Programming Error 5.8

Infinite loops occur when the loop-continuation condition in a ***while****,* ***for*** *or* ***do/while*** *structure never becomes* ***false****. To prevent this situation, make sure that there is not a semicolon immediately after the header of a* ***while*** *or* ***for*** *structure. In a counter-controlled loop, ensure that the control variable is incremented (or decremented) in the body of the loop. In a sentinel-controlled loop, ensure that the sentinel value is eventually input.*

The applet in Fig. 5.9 uses a **do/while** structure to draw 10 nested circles, using **Graphics** method **drawOval**.

```
1  // Fig. 5.9: DoWhileTest.java
2  // Using the do/while repetition structure.
3
4  // Java core packages
5  import java.awt.Graphics;
6
7  // Java extension packages
8  import javax.swing.JApplet;
9
10 public class DoWhileTest extends JApplet {
11
12    // draw lines on applet's background
13    public void paint( Graphics g )
14    {
15       // call inherited version of method paint
16       super.paint( g );
17
18       int counter = 1;
19
20       do {
21          g.drawOval( 110 - counter * 10, 110 - counter * 10,
22             counter * 20, counter * 20 );
23          ++counter;
24       } while ( counter <= 10 );  // end do/while structure
25
26    }  // end method paint
27
28 }  // end class DoWhileTest
```

Fig. 5.9 Using the **do/while** repetition structure (part 1 of 2).

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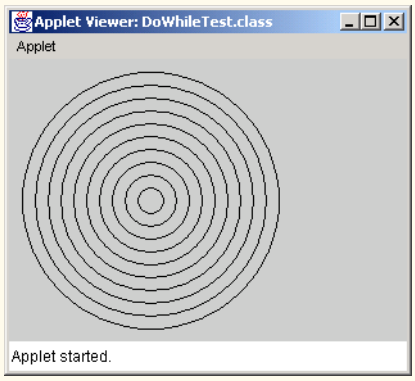

Fig. 5.9 Using the **do/while** repetition structure (part 2 of 2).

In method **paint** (lines 13–26), line 18 declares control variable **counter** and initializes it to **1**. Upon entering the **do/while** structure, lines 21–22 send the **drawOval** message to the **Graphics** object to which **g** refers. The four arguments that represent the upper left *x*-coordinate, upper left *y*-coordinate, width and height of the oval's *bounding box* (an imaginary rectangle in which the oval touches the center of all four sides of the rectangle) are calculated based on the value of **counter**. The program draws the innermost oval first. The bounding box's upper left corner for each subsequent oval moves closer to the upper left corner of the applet. At the same time, the width and height of the bounding box are increased, to ensure that each new oval contains all the previous ovals. Line 23 increments **counter**. Then, the program evaluates the loop-continuation test at the bottom of the loop. The **do/while** flowchart in Fig. 5.10 makes it clear that the program does not evaluate the loop-continuation condition until after the action executes once.

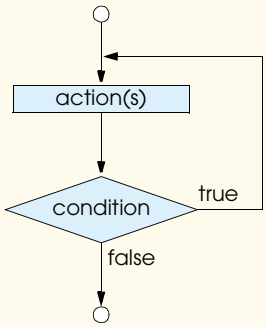

Fig. 5.10 Flowcharting the **do/while** repetition structure.

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5.7 Statements `break` and `continue`

The ***`break`*** and ***`continue`*** statements alter the flow of control. The **`break`** statement, when executed in a **`while`**, **`for`**, **`do/while`** or **`switch`** structure, causes immediate exit from that structure. Execution continues with the first statement after the structure. Common uses of the **`break`** statement are to escape early from a loop or skip the remainder of a **`switch`** structure (as in Fig. 5.7). Figure 5.11 demonstrates the **`break`** statement in a **`for`** repetition structure.

```
1  // Fig. 5.11: BreakTest.java
2  // Using the break statement in a for structure
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class BreakTest {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       String output = "";
13       int count;
14
15       // loop 10 times
16       for ( count = 1; count <= 10; count++ ) {
17
18          // if count is 5, terminate loop
19          if ( count == 5 )
20             break;  // break loop only if count == 5
21
22          output += count + " ";
23
24       }  // end for structure
25
26       output += "\nBroke out of loop at count = " + count;
27       JOptionPane.showMessageDialog( null, output );
28
29       System.exit( 0 );  // terminate application
30
31    }  // end method main
32
33 }  // end class BreakTest
```

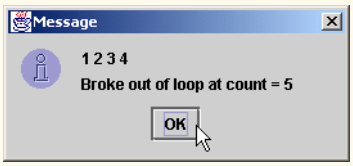

Fig. 5.11 Using the **`break`** statement in a **`for`** structure.

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When the **if** structure at line 19 in the **for** structure detects that **count** is **5**, the **break** statement at line 20 executes. This statement terminates the **for** structure, and the program proceeds to line 26 (immediately after the **for**). Line 26 completes the string to display in a message dialog at line 27. The loop fully executes its body only four times.

The **continue** statement, when executed in a **while**, **for** or **do/while** structure, skips the remaining statements in the loop body and proceeds with the next iteration of the loop. In **while** and **do/while** structures, the program evaluates the loop-continuation test immediately after the **continue** statement executes. In **for** structures, the increment expression executes, then the program evaluates the loop-continuation test. Earlier, we stated that the **while** structure could be used in most cases to represent the **for** structure. The one exception occurs when the increment expression in the **while** structure follows the **continue** statement. In this case, the increment does not execute before the program evaluates the repetition-continuation condition, so the **while** structure does not execute in the same manner as does the **for** structure. Figure 5.12 uses the **continue** statement in a **for** structure to skip the string concatenation statement (line 22) when the **if** structure (line 18) determines that the value of **count** is **5**. When the **continue** statement executes, program control continues with the increment of the control variable in the **for** structure.

Good Programming Practice 5.15

*Some programmers feel that **break** and **continue** violate structured programming. Because the effects of these statements are achievable with structured programming techniques, these programmers do not use **break** and **continue**.*

```
1  // Fig. 5.12: ContinueTest.java
2  // Using the continue statement in a for structure
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class ContinueTest {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       String output = "";
13
14       // loop 10 times
15       for ( int count = 1; count <= 10; count++ ) {
16
17          // if count is 5, continue with next iteration of loop
18          if ( count == 5 )
19             continue;  // skip remaining code in loop
20                        // only if count == 5
21
22          output += count + " ";
23
24       }  // end for structure
25
```

Fig. 5.12 Using the **continue** statement in a **for** structure (part 1 of 2).

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```
26         output += "\nUsed continue to skip printing 5";
27         JOptionPane.showMessageDialog( null, output );
28
29         System.exit( 0 );  // terminate application
30
31      } // end method main
32
33   }  // end class ContinueTest
```

Fig. 5.12 Using the **continue** statement in a **for** structure (part 2 of 2).

Performance Tip 5.3

*The **break** and **continue** statements, when used properly, perform faster than the corresponding structured techniques.*

Software Engineering Observation 5.1

There is a tension between achieving quality software engineering and achieving the best performing software. Often, one of these goals is achieved at the expense of the other. For all but the most performance-intensive situations, apply the following rule of thumb: First, make your code simple and correct; then make it fast and small, but only if necessary.

5.8 Labeled **break** and **continue** Statements

The **break** statement can break out of only an immediately enclosing **while**, **for**, **do/while** or **switch** structure. To break out of a nested set of structures, you can use the *labeled **break** statement*. This statement, when executed in a **while**, **for**, **do/while** or **switch** structure, causes immediate exit from that structure and any number of enclosing repetition structures; program execution resumes with the first statement after the enclosing *labeled block* (i.e., a set of statements enclosed in curly braces and preceded by a label). The block can be either a repetition structure (the body would be the block) or a block in which the repetition structure is the first executable code. Labeled **break** statements are commonly used to terminate nested looping structures containing **while**, **for**, **do/while** or **switch** structures. Figure 5.13 demonstrates the labeled **break** statement in a nested **for** structure.

The block (lines 14–37) begins with a *label* (an identifier followed by a colon) at line 14; here, we use the label "**stop:**." The block is enclosed in braces at the end of line 14 and line 37 and includes the nested **for** structure (lines 17–32) and the string-concatenation statement at line 35. When the **if** structure at line 23 detects that **row** is equal to **5**, the **break** statement at line 24 executes. This statement terminates both the **for** structure at line 20 and its enclosing **for** structure at line 17. The program proceeds immediately to

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line 39—the first statement after the labeled block. The outer **for** structure fully executes its body only four times. Notice that the string-concatenation statement at line 35 never executes, because it is in the labeled block's body, and the outer **for** structure never completes.

```
1  // Fig. 5.13: BreakLabelTest.java
2  // Using the break statement with a label
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class BreakLabelTest {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       String output = "";
13
14       stop: {    // labeled block
15
16          // count 10 rows
17          for ( int row = 1; row <= 10; row++ ) {
18
19             // count 5 columns
20             for ( int column = 1; column <= 5 ; column++ ) {
21
22                // if row is 5, jump to end of "stop" block
23                if ( row == 5 )
24                   break stop; // jump to end of stop block
25
26                output += "*  ";
27
28             }  // end inner for structure
29
30             output += "\n";
31
32          }  // end outer for structure
33
34          // the following line is skipped
35          output += "\nLoops terminated normally";
36
37       }  // end labeled block
38
39       JOptionPane.showMessageDialog(
40          null, output,"Testing break with a label",
41          JOptionPane.INFORMATION_MESSAGE );
42
43       System.exit( 0 );  // terminate application
44
45    }  // end method main
46
47 }  // end class BreakLabelTest
```

Fig. 5.13 Using a labeled **break** statement in a nested **for** structure (part 1 of 2).

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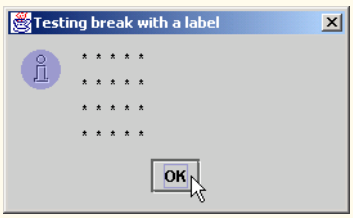

Fig. 5.13 Using a labeled **break** statement in a nested **for** structure (part 2 of 2).

The **continue** statement proceeds with the next iteration (repetition) of the immediately enclosing **while**, **for** or **do/while** structure. The *labeled* ***continue*** *statement*, when executed in a repetition structure (**while**, **for** or **do/while**), skips the remaining statements in that structure's body and any number of enclosing repetition structures and proceeds with the next iteration of the enclosing *labeled repetition structure* (i.e., a repetition structure preceded by a label). In labeled **while** and **do/while** structures, the program evaluates the loop-continuation test immediately after the **continue** statement executes. In a labeled **for** structure, the increment expression is executed, and then the loop-continuation test is evaluated. Figure 5.14 uses the labeled **continue** statement in a nested **for** structure to enable execution to continue with the next iteration of the outer **for** structure.

The labeled **for** structure (lines 14–32) starts at the **nextRow** label. When the **if** structure at line 24 in the inner **for** structure detects that **column** is greater than **row**, the **continue** statement at line 25 executes, and program control continues with the increment of the control variable of the outer **for** loop. Even though the inner **for** structure counts from 1 to 10, the number of ***** characters output on a row never exceeds the value of **row**.

Performance Tip 5.4

The program in Fig. 5.14 can be made simpler and more efficient by replacing the condition in the ***for*** *structure at line 21 with* ***column <= row*** *and removing the* ***if*** *structure at lines 24–25 from the program.*

5.9 Logical Operators

So far, we have studied only *simple conditions*, such as **count <= 10**, **total > 1000** and **number != sentinelValue**. These conditions were expressed in terms of the relational operators **>**, **<**, **>=** and **<=** and the equality operators **==** and **!=**. Each decision tested one condition. To test multiple conditions in the process of making a decision, we performed these tests in separate statements or in nested **if** or **if/else** structures.

Java provides *logical operators* to enable programmers to form more complex conditions by combining simple conditions. The logical operators are **&&** (*logical AND*), **&** (*boolean logical AND*), **||** (*logical OR*), **|** (*boolean logical inclusive OR*), **^** (*boolean logical exclusive OR*) and **!** (*logical NOT*, also called *logical negation*).

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```
1  // Fig. 5.14: ContinueLabelTest.java
2  // Using the continue statement with a label
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class ContinueLabelTest {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       String output = "";
13
14       nextRow:    // target label of continue statement
15
16          // count 5 rows
17          for ( int row = 1; row <= 5; row++ ) {
18             output += "\n";
19
20             // count 10 columns per row
21             for ( int column = 1; column <= 10; column++ ) {
22
23                // if column greater than row, start next row
24                if ( column > row )
25                   continue nextRow; // next iteration of
26                                     // labeled loop
27
28                output += "*  ";
29
30             }  // end inner for structure
31
32          }  // end outer for structure
33
34       JOptionPane.showMessageDialog(
35          null, output,"Testing continue with a label",
36          JOptionPane.INFORMATION_MESSAGE );
37
38       System.exit( 0 );  // terminate application
39
40    }  // end method main
41
42 }  // end class ContinueLabelTest
```

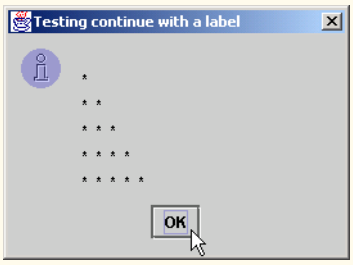

Fig. 5.14 Using a labeled **continue** statement in a nested **for** structure .

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Suppose we wish to ensure at some point in a program that two conditions are *both* **true** before we choose a certain path of execution. In this case, we can use the logical **&&** operator, as follows:

```
if ( gender == 1 && age >= 65 )
   ++seniorFemales;
```

This **if** statement contains two simple conditions. The condition **gender == 1** might be evaluated, for example, to determine if a person is a female. The condition **age >= 65** is evaluated to determine if a person is a senior citizen. The two simple conditions are evaluated first, because the precedences of **==** and **>=** are both higher than the precedence of **&&**. The **if** statement then considers the combined condition

```
gender == 1 && age >= 65
```

This condition is **true** *if and only if* both of the simple conditions are **true**. If this combined condition is indeed **true**, the **if** structure's body statement increments variable **seniorFemales** by **1**. If either or both of the simple conditions are **false**, the program skips the increment and proceeds to the statement following the **if** structure. The preceding combined condition can be made more readable by adding redundant parentheses:

```
( gender == 1 ) && ( age >= 65 )
```

The table in Fig. 5.15 summarizes the **&&** operator. The table shows all four possible combinations of **false** and **true** values for *expression1* and *expression2*. Such tables are often called *truth tables.* Java evaluates to **false** or **true** all expressions that include relational operators, equality operators and/or logical operators.

Now let us consider the || (logical OR) operator. Suppose we wish to ensure that either *or* both of two conditions are **true** before we choose a certain path of execution. In this case, we use the || operator, as in the following program segment:

```
if ( semesterAverage >= 90 || finalExam >= 90 )
   System.out.println ( "Student grade is A" );
```

This statement also contains two simple conditions. The condition **semesterAverage >= 90** evaluates to determine if the student deserves an "A" in the course because of a solid performance throughout the semester. The condition **finalExam >= 90** evaluates to determine if the student deserves an "A" in the course because of an outstanding performance on the final exam. The **if** statement then considers the combined condition

expression1	expression2	expression1 && expression2
false	false	false
false	true	false
true	false	false
true	true	true

Fig. 5.15 Truth table for the **&&** (logical AND) operator.

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```
semesterAverage >= 90 || finalExam >= 90
```

and awards the student an "A" if either or both of the simple conditions are **true**. Note that the only time the message "**Student grade is A**" is *not* printed is when both of the simple conditions are **false**. Figure 5.16 is a truth table for the logical OR operator (||).

The **&&** operator has a higher precedence than the || operator. Both operators associate from left to right. An expression containing **&&** or || operators is evaluated only until truth or falsity is known. Thus, evaluation of the expression

```
gender == 1 && age >= 65
```

stops immediately if **gender** is not equal to **1** (i.e., the entire expression is **false**) and continues if **gender** is equal to **1** (i.e., the entire expression could still be **true** if the condition **age >= 65** is **true**). This performance feature for evaluation of logical AND and logical OR expressions is called *short-circuit evaluation.*

Common Programming Error 5.9

*In expressions using operator **&&**, it is possible that a condition—we will call this the dependent condition—may require another condition to be **true** for it to be meaningful to evaluate the dependent condition. In this case, the dependent condition should be placed after the other condition, or an error might occur.*

Performance Tip 5.5

*In expressions using operator **&&**, if the separate conditions are independent of one another, make the condition that is most likely to be **false** the leftmost condition. In expressions using operator ||, make the condition that is most likely to be **true** the leftmost condition. This can reduce a program's execution time.*

The *boolean logical AND* (**&**) and *boolean logical inclusive OR* (|) operators work identically to the regular logical AND and logical OR operators, with one exception: The boolean logical operators always evaluate both of their operands (i.e., there is no short-circuit evaluation). Therefore, the expression

```
gender == 1 & age >= 65
```

evaluates **age >= 65** regardless of whether **gender** is equal to **1**. This method is useful if the right operand of the boolean logical AND or boolean logical inclusive OR operator has a required *side effect*—a modification of a variable's value. For example, the expression

expression1	expression2	expression1 || expression2
false	false	false
false	true	true
true	false	true
true	true	true

Fig. 5.16 Truth table for the || (logical OR) operator.

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```
birthday == true | ++age >= 65
```

guarantees that the condition **`++age >= 65`** will be evaluated. Thus, the variable **`age`** is incremented in the preceding expression, regardless of whether the overall expression is **`true`** or **`false`**.

Good Programming Practice 5.16

For clarity, avoid expressions with side effects in conditions. The side effects may look clever, but they are often more trouble than they are worth.

A condition containing the *boolean logical exclusive OR* (**`^`**) operator is **`true`** *if and only if one of its operands results in a* **`true`** *value and one results in a* **`false`** *value*. If both operands are **`true`** or both are **`false`**, the result of the entire condition is **`false`**. Figure 5.17 is a truth table for the boolean logical exclusive OR operator (**`^`**). This operator is also guaranteed to evaluate both of its operands (i.e., there is no short-circuit evaluation).

Java provides the **`!`** (logical negation) operator to enable a programmer to "reverse" the meaning of a condition. Unlike the logical operators **`&&`**, **`&`**, **`||`**, **`|`** and **`^`**, which combine two conditions (i.e., they are binary operators), the logical negation operator has only a single condition as an operand (i.e., they are unary operator). The logical negation operator is placed before a condition to choose a path of execution if the original condition (without the logical negation operator) is **`false`**, such as in the following program segment:

```
if ( ! ( grade == sentinelValue ) )
   System.out.println( "The next grade is " + grade );
```

The parentheses around the condition **`grade == sentinelValue`** are needed, because the logical negation operator has a higher precedence than the equality operator. Figure 5.18 is a truth table for the logical negation operator.

In most cases, the programmer can avoid using logical negation by expressing the condition differently with an appropriate relational or equality operator. For example, the previous statement may also be written as follows:

expression1	expression2	expression1 ^ expression2
`false`	`false`	`false`
`false`	`true`	`true`
`true`	`false`	`true`
`true`	`true`	`false`

Fig. 5.17 Truth table for the boolean logical exclusive OR (**`^`**) operator .

expression	!expression
`false`	`true`
`true`	`false`

Fig. 5.18 Truth table for operator **`!`** (logical negation, or logical NOT).

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```
      if ( grade != sentinelValue )
         System.out.println( "The next grade is " + grade );
```

This flexibility can help a programmer express a condition in a more convenient manner.

The application in Fig. 5.19 demonstrates all of the logical operators and boolean logical operators by producing their truth tables. The program uses string concatenation to create the string that is displayed in a **JTextArea**.

```
1  // Fig. 5.19: LogicalOperators.java
2  // Demonstrating the logical operators
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class LogicalOperators {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       // create JTextArea to display results
13       JTextArea outputArea = new JTextArea( 17, 20 );
14
15       // attach JTextArea to a JScrollPane so user can
16       // scroll through results
17       JScrollPane scroller = new JScrollPane( outputArea );
18
19       String output;
20
21       // create truth table for && operator
22       output = "Logical AND (&&)" +
23          "\nfalse && false: " + ( false && false ) +
24          "\nfalse && true: " + ( false && true ) +
25          "\ntrue && false: " + ( true && false ) +
26          "\ntrue && true: " + ( true && true );
27
28       // create truth table for || operator
29       output += "\n\nLogical OR (||)" +
30          "\nfalse || false: " + ( false || false ) +
31          "\nfalse || true: " + ( false || true ) +
32          "\ntrue || false: " + ( true || false ) +
33          "\ntrue || true: " + ( true || true );
34
35       // create truth table for & operator
36       output += "\n\nBoolean logical AND (&)" +
37          "\nfalse & false: " + ( false & false ) +
38          "\nfalse & true: " + ( false & true ) +
39          "\ntrue & false: " + ( true & false ) +
40          "\ntrue & true: " + ( true & true );
41
42       // create truth table for | operator
43       output += "\n\nBoolean logical inclusive OR (|)" +
44          "\nfalse | false: " + ( false | false ) +
45          "\nfalse | true: " + ( false | true ) +
```

Fig. 5.19 Demonstrating the logical operators (part 1 of 2).

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```
46             "\ntrue | false: " + ( true | false ) +
47             "\ntrue | true: " + ( true | true );
48
49          // create truth table for ^ operator
50          output += "\n\nBoolean logical exclusive OR (^)" +
51             "\nfalse ^ false: " + ( false ^ false ) +
52             "\nfalse ^ true: " + ( false ^ true ) +
53             "\ntrue ^ false: " + ( true ^ false ) +
54             "\ntrue ^ true: " + ( true ^ true );
55
56          // create truth table for ! operator
57          output += "\n\nLogical NOT (!)" +
58             "\n!false: " + ( !false ) +
59             "\n!true: " + ( !true );
60
61          outputArea.setText( output );  // place results in JTextArea
62
63          JOptionPane.showMessageDialog( null, scroller,
64             "Truth Tables", JOptionPane.INFORMATION_MESSAGE );
65
66          System.exit( 0 );  // terminate application
67
68       }  // end method main
69
70    }  // end class LogicalOperators
```

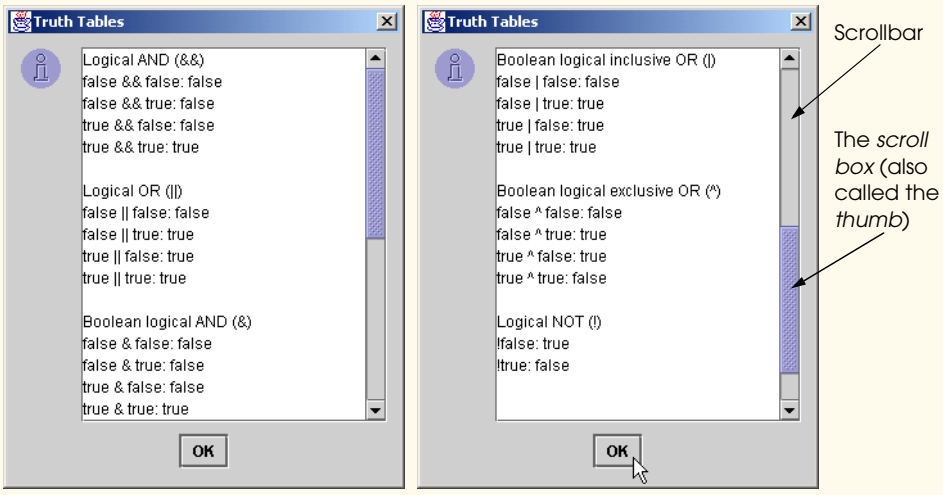

Fig. 5.19 Demonstrating the logical operators (part 2 of 2).

In the output of Fig. 5.19, the strings "true" and "false" indicate **true** and **false** for the operands in each condition. The result of the condition is shown as **true** or **false**. Note that when you concatenate a **boolean** value with a **String**, Java automatically adds the string "false" or "true," based on the **boolean** value.

Line 13 in method **main** creates a **JTextArea**. The numbers in the parentheses indicate that the **JTextArea** has 17 rows and 20 columns. Line 17 declares **JScrollPane** reference **scroller** and initializes it with a new **JScrollPane** object. Class

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JScrollPane (from package **javax.swing**) provides a GUI component with scrolling functionality. A **JScrollPane** object is initialized with the GUI component for which it will provide scrolling functionality (**outputArea** in this example). This initialization attaches the GUI component to the **JScrollPane**. When you execute this application, notice the *scrollbar* on the right side of the **JTextArea**. You can click the *arrows* at the top or bottom of the scrollbar to scroll up or down, respectively, through the text in the **JTextArea** one line at a time. You can also drag the *scroll box* (also called the *thumb*) up or down to scroll through the text rapidly.

Lines 22–59 build the **output** string that is displayed in the **outputArea**. Line 61 uses method **setText** to replace the text in **outputArea** with the **output** string. Lines 63–64 display a message dialog. The second argument, **scroller**, indicates that the **scroller** (and the **outputArea** attached to it) should be displayed as the message in the message dialog.

The chart in Fig. 5.20 shows the precedence and associativity of the Java operators introduced up to this point. The operators are shown from top to bottom in decreasing order of precedence.

5.10 Structured Programming Summary

Just as architects design buildings by employing the collective wisdom of their profession, so should programmers design programs. Our field is younger than architecture is, and our collective wisdom is considerably sparser. We have learned that structured programming produces programs that are easier than unstructured programs to understand and hence are easier to test, debug, modify and even prove correct in a mathematical sense.

Operators	Associativity	Type
`()`	left to right	parentheses
`++ --`	right to left	unary postfix
`++ -- + - ! (`*type*`)`	right to left	unary
`* / %`	left to right	multiplicative
`+ -`	left to right	additive
`< <= > >=`	left to right	relational
`== !=`	left to right	equality
`&`	left to right	boolean logical AND
`^`	left to right	boolean logical exclusive OR
`|`	left to right	boolean logical inclusive OR
`&&`	left to right	logical AND
`||`	left to right	logical OR
`?:`	right to left	conditional
`= += -= *= /= %=`	right to left	assignment

Fig. 5.20 Precedence and associativity of the operators discussed so far.

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Figure 5.21 summarizes Java's control structures. Small circles are used in the figure to indicate the single entry and single exit points of each structure. Connecting individual flowchart symbols arbitrarily can lead to unstructured programs. Therefore, the programming profession has chosen to combine flowchart symbols to form a limited set of control structures, and to build structured programs by properly combining control structures in two simple ways.

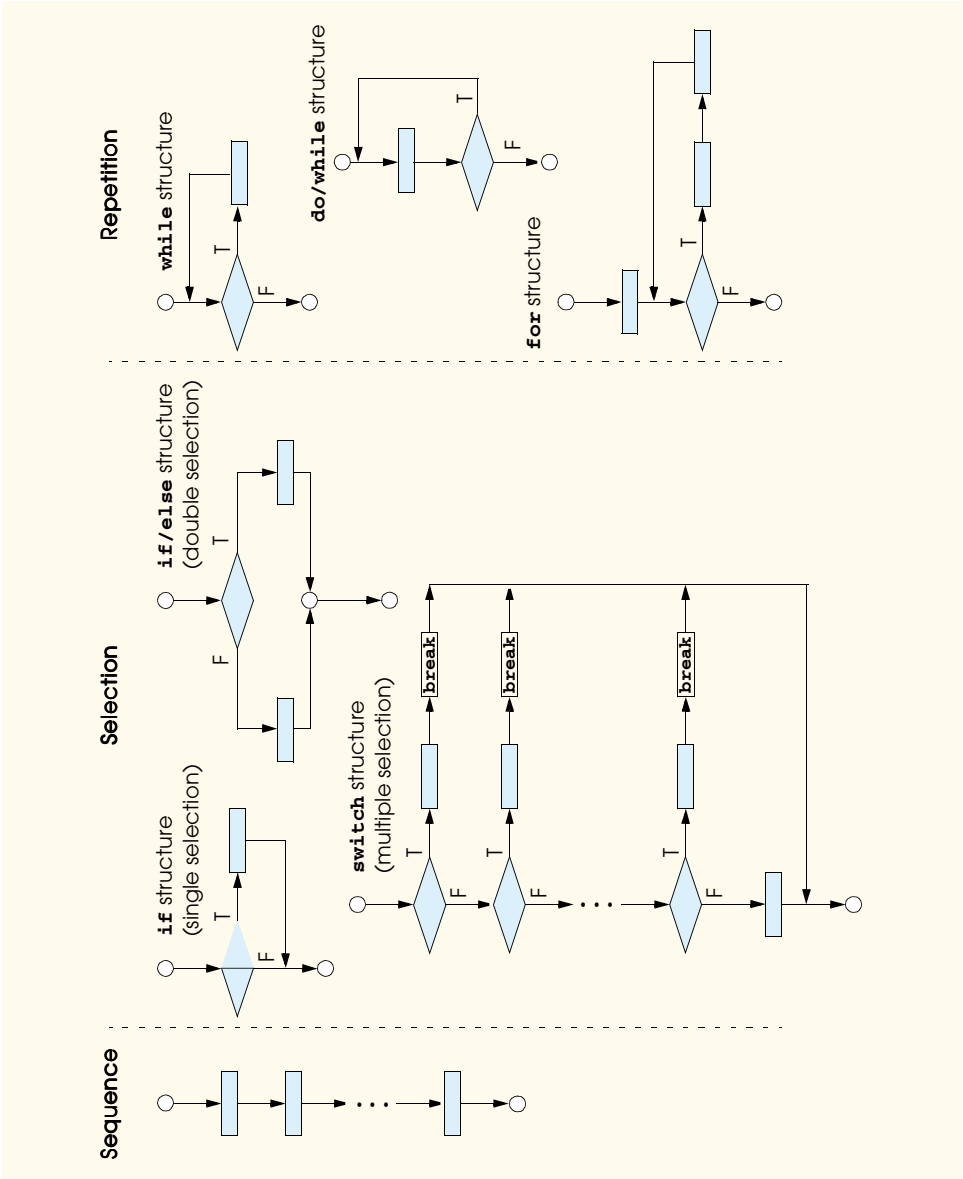

Fig. 5.21 Java's single-entry/single-exit control structures.

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For simplicity, only single-entry/single-exit control structures are used; there is only one way to enter and only one way to exit each control structure. Connecting control structures in sequence to form structured programs is simple: The exit point of one control structure is connected to the entry point of the next control structure (i.e., the control structures are simply placed one after another in a program); we have called this method "control-structure stacking." The rules for forming structured programs also allow for control-structure nesting.

Figure 5.22 shows the rules for forming properly structured programs. The rules assume that the rectangle flowchart symbol may be used to indicate any action, including input/output.

Applying the rules of Fig. 5.22 always results in a structured flowchart with a neat, building-block-like appearance (Fig. 5.23). For example, repeatedly applying Rule 2 to the simplest flowchart results in a structured flowchart containing many rectangles in sequence (Fig. 5.24). Rule 2 generates a stack of control structures; so let us call Rule 2 the *stacking rule*. [*Note*: The symbols at the top and bottom of Fig. 5.23 represent the beginning and end of a program, respectively.]

Rule 3 is called the *nesting rule*. Repeatedly applying Rule 3 to the simplest flowchart results in a flowchart with neatly nested control structures. For example, in Fig. 5.25, the rectangle in the simplest flowchart is first replaced with a double-selection (**`if/else`**) structure. Then, Rule 3 is applied again to both of the rectangles in the double-selection structure, replacing each of the rectangles with double-selection structures. The dashed boxes around each of the double-selection structures represent the rectangle that was replaced with a double-selection structure.

Rules for Forming Structured Programs

1) Begin with the "simplest flowchart" (Fig. 5.23).
2) Any rectangle (action) can be replaced by two rectangles (actions) in sequence.
3) Any rectangle (action) can be replaced by any control structure (sequence, **`if`**, **`if/else`**, **`switch`**, **`while`**, **`do/while`** or **`for`**).
4) Rules 2 and 3 may be applied as often as you like and in any order.

Fig. 5.22 Rules for forming structured programs.

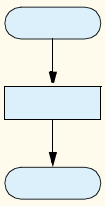

Fig. 5.23 The simplest flowchart.

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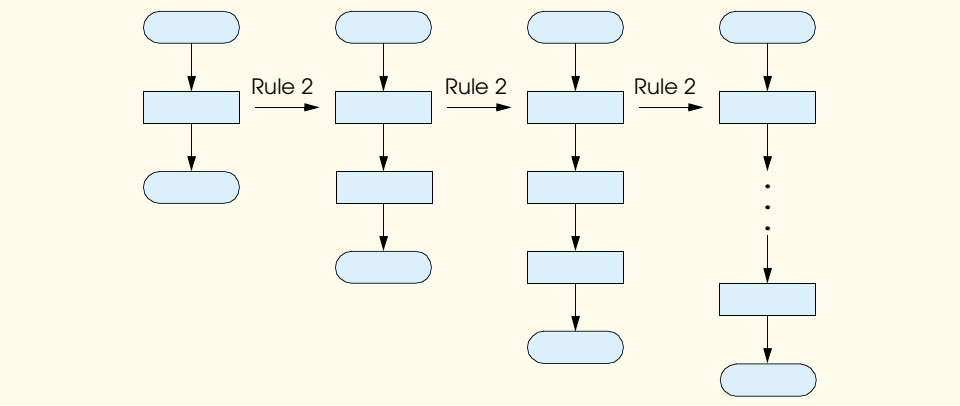

Fig. 5.24 Repeatedly applying Rule 2 of Fig. 5.22 to the simplest flowchart.

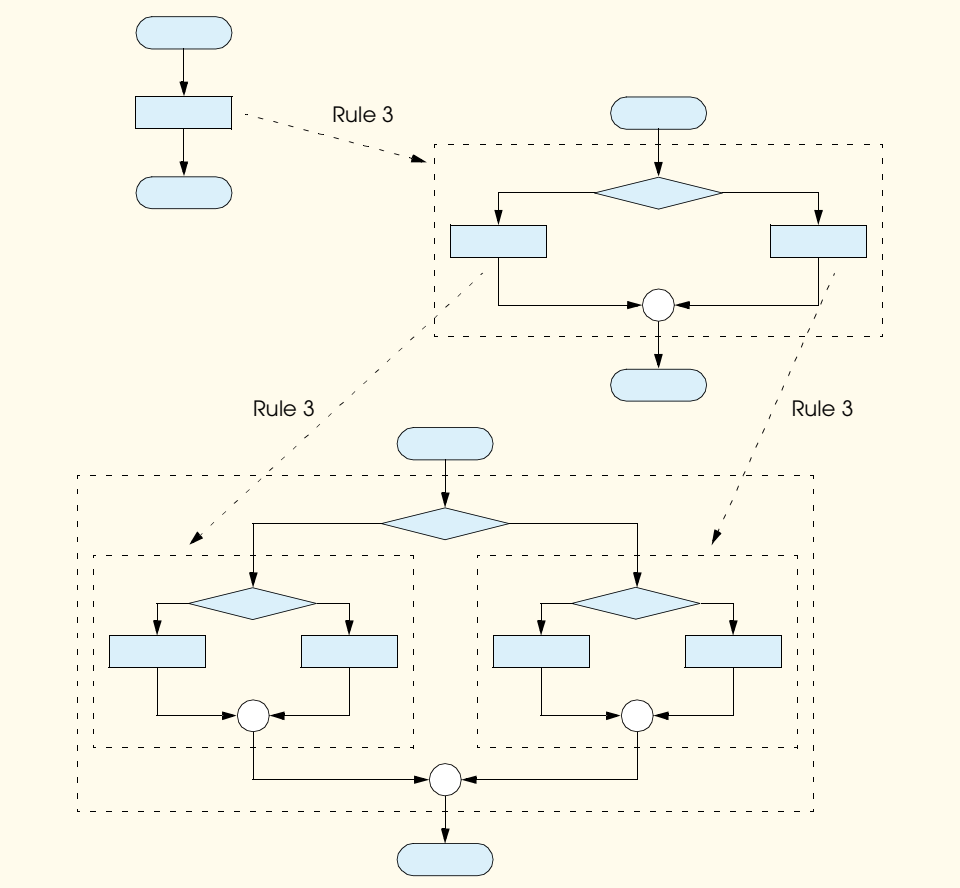

Fig. 5.25 Applying Rule 3 of Fig. 5.22 to the simplest flowchart.

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Rule 4 generates larger, more involved and more deeply nested structures. The flowcharts that emerge from applying the rules in Fig. 5.22 constitute the set of all possible structured flowcharts and hence the set of all possible structured programs.

The beauty of the structured approach is that we use only seven simple single-entry/single-exit pieces and we assemble them in only two simple ways. Figure 5.26 shows the kinds of stacked building blocks that emerge from applying Rule 2 and the kinds of nested building blocks that emerge from applying Rule 3. The figure also shows the kind of overlapped building blocks that cannot appear in structured flowcharts (because of the elimination of the **`goto`** statement).

If the rules in Fig. 5.22 are followed, you cannot create an unstructured flowchart (such as that in Fig. 5.27). If you are uncertain if a particular flowchart is structured, apply the rules of Fig. 5.22 in reverse to try to reduce the flowchart to the simplest flowchart. If the flowchart is reducible to the simplest flowchart, the original flowchart is structured; otherwise, it is not.

Structured programming promotes simplicity. Bohm and Jacopini have shown that only three forms of control are needed—sequence, selection and repetition.

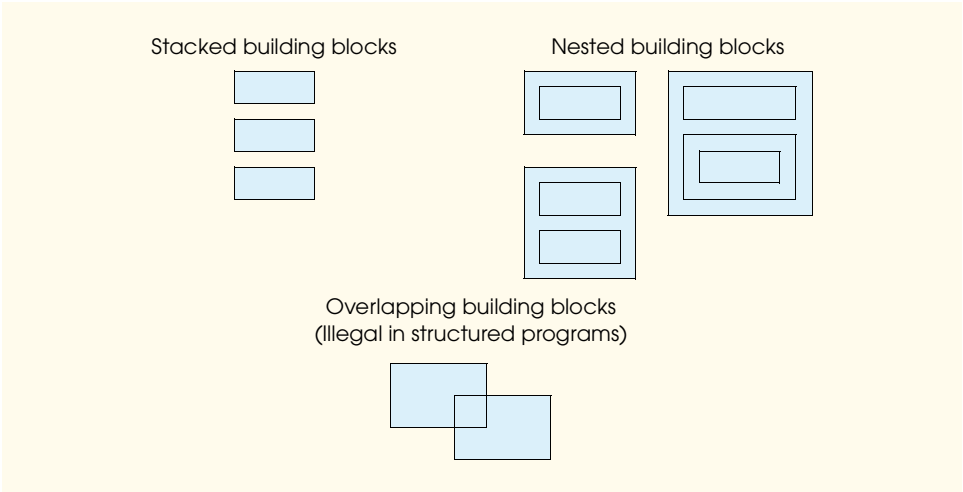

Fig. 5.26 Stacked, nested and overlapped building blocks.

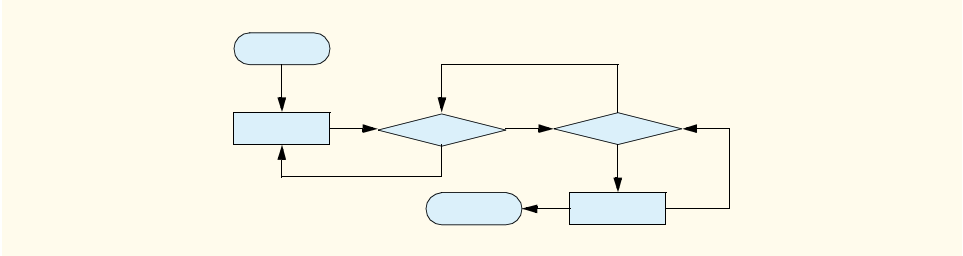

Fig. 5.27 An unstructured flowchart.

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Sequence is trivial. Selection is implemented in one of three ways:

- an **`if`** structure (single selection),
- an **`if`**/**`else`** structure (double selection), or
- a **`switch`** structure (multiple selection).

In fact, it is straightforward to prove that the **`if`** structure is sufficient for any form of selection; everything that can be done with the **`if`**/**`else`** structure and the **`switch`** structure can be implemented by combining **`if`** structures (although perhaps not as elegantly).

Repetition is implemented in one of three ways:

- a **`while`** structure,
- a **`do`**/**`while`** structure, or
- a **`for`** structure.

It is straightforward to prove that the **`while`** structure is sufficient to provide any form of repetition. Everything that can be done with the **`do`**/**`while`** structure and the **`for`** structure can be done with the **`while`** structure (although perhaps not as elegantly).

Combining these results illustrates that any form of control ever needed in a Java program can be expressed in terms of

- a sequence,
- a **`if`** structure (selection), or
- a **`while`** structure (repetition).

And these control structures can be combined in only two ways—stacking and nesting. Indeed, structured programming promotes simplicity.

In this chapter, we have discussed how to compose programs from control structures containing actions and decisions. In Chapter 6, we introduce another program structuring unit, called the *method*. We will learn to compose large programs by combining methods that, in turn, are composed of control structures. We will also discuss how methods promote software reusability. In Chapter 8, we discuss in more detail Java's other program-structuring unit, called the *class*. We will then create objects from classes and proceed with our treatment of object-oriented programming.

5.11 (Optional Case Study) Thinking About Objects: Identifying Objects' States and Activities

In "Thinking About Objects," Section 4.14, we determined many of the class attributes needed to implement the elevator simulator and added them to the class diagram of Fig. 4.18. In this section, we show how these attributes represent an object's *state*, or condition. We identify the set of possible states that our objects may occupy and discuss how these objects change state in response to *messages*. We also discuss the workflow, or the *activities*, that an object performs in our elevator simulation.

Statechart Diagrams

Objects in a system have *states*. A state describes the condition of an object at a given time. *Statechart diagrams* (also called *state diagrams*) give us a way to express how, and under what conditions, the objects in a system change state. Unlike the class and object

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diagrams presented in earlier case-study sections, statechart diagrams model the behavior of the system.

Figure 5.28 is a simple statechart diagram that models the states of an object of either class **`FloorButton`** or class **`ElevatorButton`**. The UML represents each state in a statechart diagram as a *rounded rectangle* with the name of the state placed inside the rectangle. A *solid circle* with an attached arrowhead designates the initial state (in this case, the "Not pressed" state). Notice that this statechart diagram models the **`boolean`** attribute **`pressed`** in the class diagram of Fig. 4.18. The attribute is initialized to **`false`**, or the "Not pressed" state according to the statechart diagram.

The arrows indicate *transitions* between states. An object can transition from one state to another in response to a *message*. For example, the **`FloorButton`** and **`ElevatorButton`** objects change from the "Not pressed" state to the "Pressed" state in response to a **`buttonPressed`** message, and the **`pressed`** attribute changes to a value of **`true`**. The name of the message that causes a transition is written near the line that corresponds to that transition. (We explain messages in Section 7.10 and Section 10.22.)

Objects from other classes, such as **`Light`**, **`Elevator`** and **`Person`**, have similar statechart diagrams. Class **`Light`** has an "on" state or an "off" state—transitions between these states occur as a result of "turn on" and "turn off" events, respectively. Class **`Elevator`** and class **`Person`** each have a "moving" state and a "waiting" state—transitions between these states occur as a result of "start moving" and "stop moving" events, respectively.

Activity Diagrams

The *activity diagram* is similar to the statechart diagram in that they both model aspects of system behavior. Unlike a statechart diagram, an activity diagram models an object's workflow during program execution. An activity diagram is a flowchart that models the *actions* the object will perform and in what order. The activity diagram in Fig. 5.29 models the activities of a person. The diagram begins with the person moving toward the floor button. If the door is open, the person waits for the current elevator passenger (if one exists) to exit then enters the elevator.[1] If the door is closed, the person presses the floor button and waits for the elevator to open the door. When the door opens, the person waits for the elevator passenger to exit (if one exists) then enters the elevator. The person presses the elevator button, which causes the elevator to move to the other floor, unless the elevator already services that floor; the person then waits for the doors to re-open and exits the elevator after the doors open.

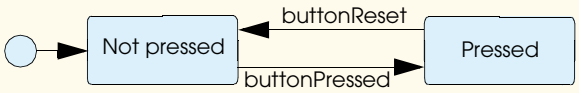

Fig. 5.28 Statechart diagram for **`FloorButton`** and **`ElevatorButton`** objects.

1. We use *multithreading* and **`synchronized`** *methods* in Section 15.12 to guarantee that the passenger riding the elevator will exit before the person waiting for the elevator will enter.

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The UML represents activities as ovals in activity diagrams. The name of the activity is placed inside the oval. An arrow connects two activities, indicating the order in which the activities are performed. As with statechart diagrams, the *solid circle* indicates the starting activity. In this case, the person moving toward the floor button is the starting activity. The activity flow arrives at a *branch* (indicated by the *small diamond symbol*) after the person moves to the floor button. This point determines the next activity based on the associated *guard condition* (in square brackets above the transition), which states that the transition occurs if this condition is met. For example, in Fig. 5.29, if the floor door is closed, the person presses the floor button, waits for the door to open, waits for the passenger (if there is one) to exit the elevator, then enters the elevator. However, if the floor door is open, the person waits for the passenger (if there is one) to exit the elevator, then enters the elevator. Regardless of whether the floor door was open or closed at the last diamond symbol, the person now presses the elevator button (which causes the doors to close and the elevator to move to the other floor), the person waits for the elevator door to open—when this door opens, the person exits the elevator. Activity diagrams are similar to the flowcharts for control structures presented in Chapters 4 and 5—both diagram types employ diamond symbols to alter the flow of control between activities.

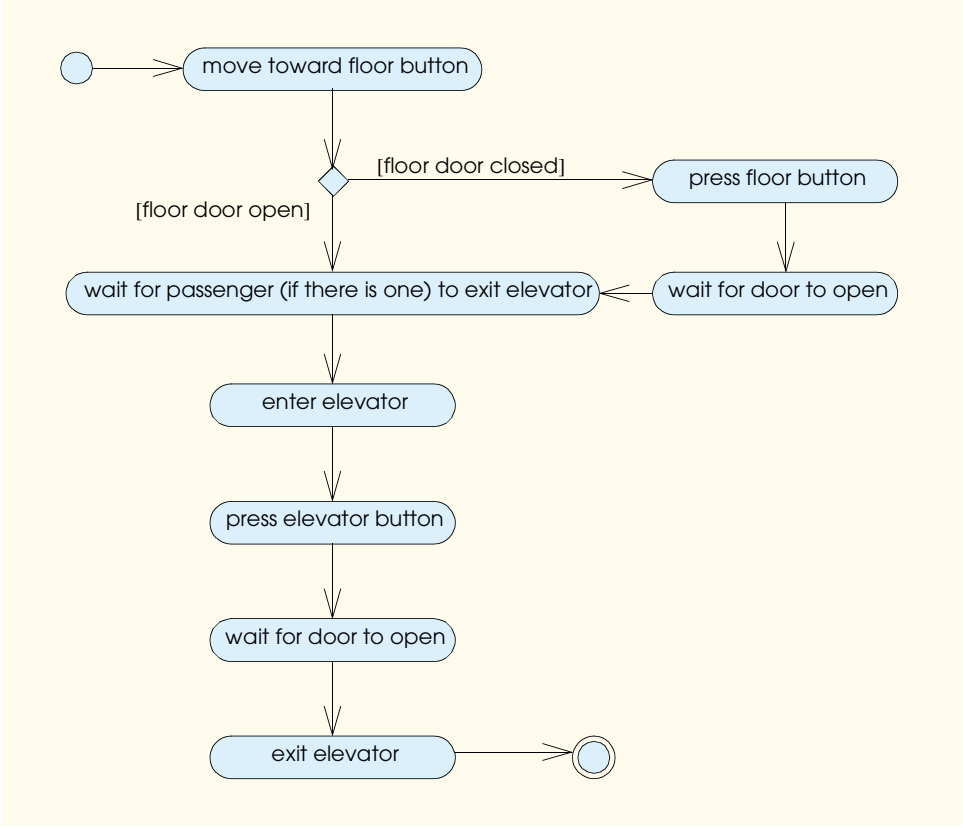

Fig. 5.29 Activity diagram for a **`Person`** object.

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Figure 5.30 shows an activity diagram for the elevator. The diagram begins when a button is pressed. If the button is an elevator button, the elevator sets **`summoned`** to false (we explain this **`boolean`** variable in a moment), closes the elevator door, moves to the other floor, resets the elevator button, rings the bell and opens the elevator door. If the button is a floor button, the next branch determines the next transition, based on whether the elevator is moving. If the elevator is idle, the next branch determines which floor button generated the request. If the request originated from the current floor on which the elevator is located, the elevator resets its button, rings its bell and opens its door. If the request originated from the opposite floor, the elevator closes the door and moves to the opposite (destination) floor, where the elevator resets its button, rings its bell and opens its door. Now consider the activity if the elevator is moving. A separate branch determines which floor button generated the request. If the request originated from the destination floor, the elevator continues traveling to that floor. If the request originated from the floor from which the elevator departed, the elevator continues traveling to the destination floor, but must remember to return to the requesting floor. The **`summoned`** attribute, originally displayed in Fig. 4.18, is set to **`true`** so that the elevator knows to return to the other floor after the elevator opens its door.

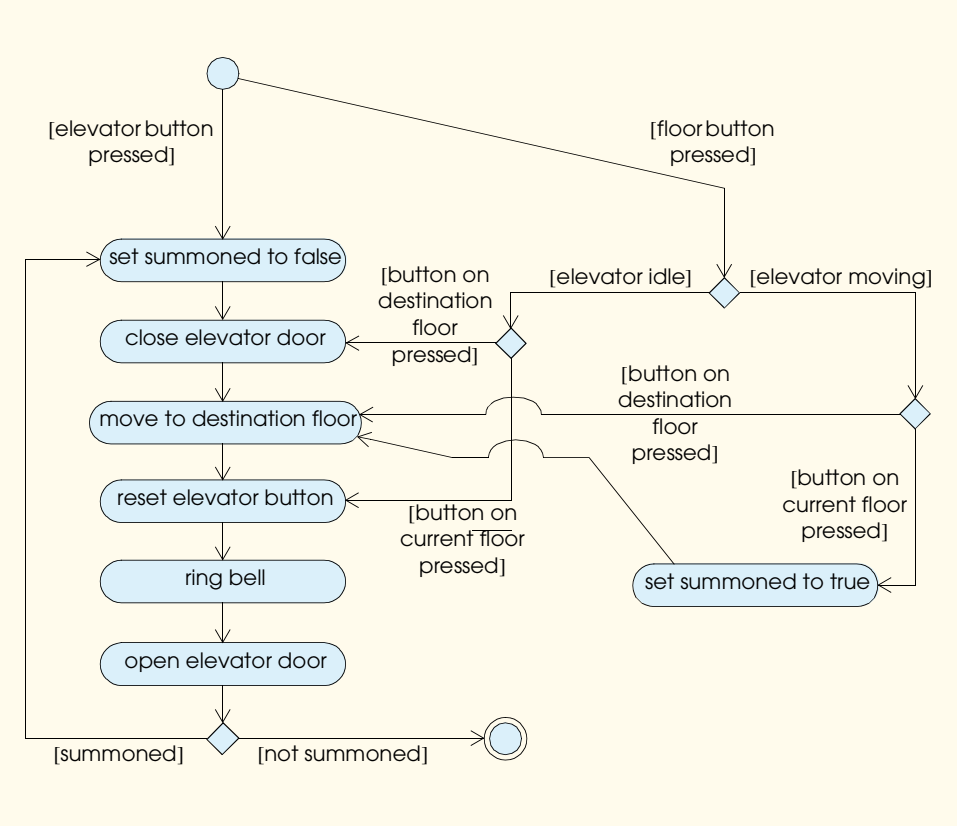

Fig. 5.30 Activity diagram for the **`Elevator`** object.

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We have taken the first steps to modeling the behavior of the system and have shown how the attributes of an object determine that object's activity. In "Thinking About Objects," Section 6.17, we investigate the behaviors for all classes to give a more accurate interpretation of the system behavior by "filling in" the final compartment for the classes in our class diagram.

SUMMARY

- The **for** repetition structure handles all of the details of counter-controlled repetition. The general format of the **for** structure is

```
for (expression1; expression2; expression3)
    statement
```

  where *expression1* initializes the loop's control variable, *expression2* is the loop-continuation condition and *expression3* modifies the control variable, so that the loop-continuation condition eventually becomes **false**.
- A **JTextArea** is a GUI component that is capable of displaying many lines of text.
- Method **setText** replaces the text in a **JTextArea**. Method **append** adds text to the end of the text in a **JTextArea**.
- **NumberFormat static** method **getCurrencyInstance** returns a **NumberFormat** object that can format numeric values as currency. The argument **Locale.US** indicates that the currency values should be displayed starting with a dollar sign ($), use a decimal point to separate dollars and cents and use a comma to delineate thousands.
- Class **Locale** provides constants that can be used to customize programs to represent currency values for other countries, so that currency formats are displayed properly for each locale.
- Class **NumberFormat** is located in package **java.text**.
- Class **Locale** is located in package ***java.util***.
- An interesting feature of class **JOptionPane** is that the message it displays with **showMessageDialog** can be a **String** or a GUI component, such as a **JTextArea**.
- The **switch** structure handles a series of decisions in which a particular variable or expression is tested for values it may assume, and different actions are taken. In most programs, it is necessary to include a **break** statement after the statements for each **case**. Several **case**s can execute the same statements by listing the **case** labels together before the statements. The **switch** structure can only test for constant integral expressions.
- The **do/while** repetition structure tests the loop-continuation condition at the end of the loop, so the body of the loop will be executed at least once. The format for the **do/while** structure is

```
do {
    statement
} while (condition);
```

- The **break** statement, when executed in one of the repetition structures (**for**, **while** and **do/while**), causes immediate exit from the structure.
- The **continue** statement, when executed in one of the repetition structures (**for**, **while** and **do/while**), skips any remaining statements in the body of the structure and proceeds with the test for the next iteration of the loop.
- To break out of a nested set of structures, use the labeled **break** statement. This statement, when executed in a **while**, **for**, **do/while** or **switch** structure, causes immediate exit from that

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structure and any number of enclosing repetition structures; program execution resumes with the first statement after the enclosing labeled block.

- The labeled **`continue`** statement, when executed in a repetition structure (**`while`**, **`for`** or **`do`**/**`while`**), skips the remaining statements in that structure's body and any number of enclosing repetition structures and proceeds with the next iteration of the enclosing labeled repetition structure.
- Logical operators may be used to form complex conditions by combining conditions. The logical operators are **`&&`**, **`&`**, **`||`**, **`|`**, **`^`** and **`!`**, meaning logical AND, boolean logical AND, logical OR, boolean logical inclusive OR, boolean logical exclusive OR and logical NOT (negation), respectively.
- Class **`JScrollPane`** provides a GUI component with scrolling functionality.

TERMINOLOGY

`!` operator
`&&` operator
`||` operator
`append` method of class **`JTextArea`**
boolean logical AND (**`&`**)
boolean logical exclusive OR (**`^`**)
boolean logical inclusive OR (**`|`**)
`break`
`case` label
`continue`
counter-controlled repetition
`default` case in **`switch`**
definite repetition
`do`/**`while`** repetition structure
`for` repetition structure
infinite loop
`java.text` package
`java.util` package
`JScrollPane` class
`JTextArea` class
labeled **`break`** statement
labeled block
labeled **`continue`** statement
labeled repetition structure
`Locale` class
`Locale.US`
logical AND (**`&&`**)
logical negation (**`!`**)
logical operators
logical OR (**`||`**)
long
loop-continuation condition
multiple selection
nested control structures
`NumberFormat` class
off-by-one error
repetition structures
scroll box
scrollbar
short-circuit evaluation
single-entry/single-exit control structures
stacked control structures
`switch` selection structure
thumb of a scrollbar
`while` repetition structure

SELF-REVIEW EXERCISES

5.1 State whether each of the following is true or false. If false, explain why.

a) The **`default`** case is required in the **`switch`** selection structure.
b) The **`break`** statement is required in the default case of a **`switch`** selection structure.
c) The expression **`( x > y && a < b )`** is true if either **`x > y`** is true or **`a < b`** is true.
d) An expression containing the **`||`** operator is true if either or both of its operands is true.

5.2 Write a Java statement or a set of Java statements to accomplish each of the following tasks:

a) Sum the odd integers between 1 and 99, using a **`for`** structure. Assume that the integer variables **`sum`** and **`count`** have been declared.
b) Calculate the value of **`2.5`** raised to the power of **`3`**, using the **`pow`** method.
c) Print the integers from 1 to 20, using a **`while`** loop and the counter variable **`x`**. Assume that the variable **`x`** has been declared, but not initialized. Print only five integers per line. [*Hint*: Use the calculation **`x % 5`**. When the value of this expression is 0, print a newline character; otherwise, print a tab character. Assume that this code is an application; use

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the `System.out.println()` method to output the newline character, and use the `System.out.print( '\t' )` method to output the tab character.]

d) Repeat Exercise 5.2 (c), using a `for` structure.

5.3 Find the error in each of the following code segments, and explain how to correct it:

a)
```
x = 1;

while ( x <= 10 );
   x++;
}
```

b)
```
for ( y = .1; y != 1.0; y += .1 )
   System.out.println( y );
```

c)
```
switch ( n ) {
   case 1:
      System.out.println( "The number is 1" );
   case 2:
      System.out.println( "The number is 2" );
      break;
   default:
      System.out.println( "The number is not 1 or 2" );
      break;
}
```

d) The following code should print the values 1 to 10.
```
n = 1;

while ( n < 10 )
   System.out.println( n++ );
```

ANSWERS TO SELF-REVIEW EXERCISES

5.1 a) False. The `default` case is optional. If no default action is needed, then there is no need for a `default` case. b) False. The `break` statement is used to exit the `switch` structure. The `break` statement is not required for the last case in a `switch` structure. c) False. Both of the relational expressions must be true for the entire expression to be true when using the `&&` operator. d) True.

5.2 The answers to Exercise 5.2 are as follows:

a)
```
sum = 0;
for ( count = 1; count <= 99; count += 2 )
   sum += count;
```

b)
```
Math.pow( 2.5, 3 )
```

c)
```
x = 1;

while ( x <= 20 ) {
   System.out.print( x );

   if ( x % 5 == 0 )
      System.out.println();
   else
      System.out.print( '\t' );

   ++x;
}
```

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d)
```
for ( x = 1; x <= 20; x++ ) {
      System.out.print( x );

   if ( x % 5 == 0 )
      System.out.println();
   else
      System.out.print( '\t' );
}
```

or

```
for ( x = 1; x <= 20; x++ )

   if ( x % 5 == 0 )
      System.out.println( x );
   else
      System.out.print( x + "\t" );
```

5.3 The answers to Exercise 5.3 are as follows:

a) Error: The semicolon after the **`while`** header causes an infinite loop, and there is a missing left brace.
Correction: Replace the semicolon by a **`{`**, or remove both the **`;`** and the **`}`**.

b) Error: Using a floating-point number to control a **`for`** repetition structure may not work, because floating-point numbers are represented only approximately by most computers.
Correction: Use an integer, and perform the proper calculation in order to get the values you desire:
```
for ( y = 1; y != 10; y++ )
   System.out.println( ( float ) y / 10 );
```

c) Error: Missing **`break`** statement in the statements for the first **`case`**.
Correction: Add a **`break`** statement at the end of the statements for the first **`case`**. Note that this omission is not necessarily an error if the programmer wants the statement of **`case 2:`** to execute every time the **`case 1:`** statement executes.

d) Error: Improper relational operator used in the **`while`** repetition-continuation condition.
Correction: Use **`<=`** rather than **`<`**, or change **`10`** to **`11`**.

EXERCISES

5.4 Find the error(s) in each of the following segments of code:

a)
```
For ( x = 100, x >= 1, x++ )
   System.out.println( x );
```

b) The following code should print whether integer **`value`** is odd or even:
```
switch ( value % 2 ) {

   case 0:
      System.out.println( "Even integer" );

   case 1:
      System.out.println( "Odd integer" );
}
```

c) The following code should output the odd integers from 19 to 1:
```
for ( x = 19; x >= 1; x += 2 )
  System.out.println( x );
```

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d) The following code should output the even integers from 2 to 100:

```
counter = 2;

do {
   System.out.println( counter );
   counter += 2;
} While ( counter < 100 );
```

5.5 What does the following program do?

```
1  public class Printing {
2
3     public static void main( String args[] )
4     {
5        for ( int i = 1; i <= 10; i++ ) {
6
7           for ( int j = 1; j <= 5; j++ )
8              System.out.print( '@' );
9
10          System.out.println();
11
12       }
13
14    }
15
16 }
```

5.6 Write an application that finds the smallest of several integers. Assume that the first value read specifies the number of values to input from the user.

5.7 Write an application that calculates the product of the odd integers from 1 to 15, and then displays the results in a message dialog.

5.8 The *factorial* method is used frequently in probability problems. The factorial of a positive integer *n* (written *n!* and pronounced "n factorial") is equal to the product of the positive integers from 1 to *n*. Write an application that evaluates the factorials of the integers from 1 to 5. Display the results in tabular format in a **`JTextArea`** that is displayed on a message dialog. What difficulty might prevent you from calculating the factorial of 20?

5.9 Modify the compound-interest program of Fig. 5.6 to repeat its steps for interest rates of 5, 6, 7, 8, 9 and 10%. Use a **`for`** loop to vary the interest rate. Add scrolling functionality to the **`JTextArea`**, so you can scroll through all the output.

5.10 Write an application that displays the following patterns separately one below the other. Use **`for`** loops to generate the patterns. All asterisks (**`*`**) should be printed by a single statement of the form **`System.out.print( '*' );`**. (This statement causes the asterisks to print side by side.) A statement of the form **`System.out.println();`** can be used to position to the next line. A statement of the form **`System.out.print( ' ' );`** can be used to display a space for the last two patterns. There should be no other output statements in the program. [*Hint*: The last two patterns require that each line begin with an appropriate number of blank spaces.]

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(a)

```
*
**
***
****
*****
******
*******
********
*********
**********
```

(b)

```
**********
*********
********
*******
******
*****
****
***
**
*
```

(c)

```
**********
 *********
  ********
   *******
    ******
     *****
      ****
       ***
        **
         *
```

(d)

```
         *
        **
       ***
      ****
     *****
    ******
   *******
  ********
 *********
**********
```

5.11 One interesting application of computers is drawing graphs and bar charts (sometimes called "histograms"). Write an applet that reads five numbers, each between 1 and 30. For each number read, your program should draw a line containing that number of adjacent asterisks. For example, if your program reads the number 7, it should display **`*******`**.

5.12 A mail-order house sells five different products whose retail prices are as follows: product 1, $2.98; product 2, $4.50; product 3, $9.98; product 4, $4.49; and product 5, $6.87. Write an application that reads a series of pairs of numbers as follows:

a) product number;
b) quantity sold for one day.

Your program should use a **`switch`** structure to help determine the retail price for each product. It should calculate and display the total retail value of all products sold last week. Use a **`TextField`** to obtain the product number from the user. Use a sentinel-controlled loop to determine when the program should stop looping and display the final results.

5.13 Modify the program in Fig. 5.6 to use only integers to calculate the compound interest. [*Hint*: Treat all monetary amounts as integral numbers of pennies. Then "break" the result into its dollar portion and cents portion by using the division and modulus operations, respectively. Insert a period between the dollars and the cents portions.]

5.14 Assume that **`i = 1`**, **`j = 2`**, **`k = 3`** and **`m = 2`**. What does each of the following statements print?

a) **`System.out.println( i == 1 );`**
b) **`System.out.println( j == 3 );`**
c) **`System.out.println( i >= 1 && j < 4 );`**
d) **`System.out.println( m <= 99 & k < m );`**
e) **`System.out.println( j >= i || k == m );`**
f) **`System.out.println( k + m < j | 3 - j >= k );`**
g) **`System.out.println( !( k > m ) );`**

5.15 Write an application that prints a table of the binary, octal, and hexadecimal equivalents of the decimal numbers in the range 1 through 256. If you are not familiar with these number systems, read Appendix E first. Place the results in a **`JTextArea`** with scrolling functionality. Display the **`JTextArea`** in a message dialog.

5.16 Calculate the value of π from the infinite series

$$\pi = 4 - \frac{4}{3} + \frac{4}{5} - \frac{4}{7} + \frac{4}{9} - \frac{4}{11} + \cdots$$

Print a table that shows the value of π approximated by one term of this series, by two terms, by three terms, etc. How many terms of this series do you have to use before you first get 3.14? 3.141? 3.1415? 3.14159?

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5.17 (*Pythagorean Triples*) A right triangle can have sides whose lengths are all integers. The set of three integer values for the lengths of the sides of a right triangle is called a Pythagorean triple. The lengths of the three sides must satisfy the relationship that the sum of the squares of two of the sides is equal to the square of the hypotenuse. Write an application to find all Pythagorean triples for **side1**, **side2** and the **hypotenuse**, all no larger than 500. Use a triple-nested **for** loop that tries all possibilities. This method is an example of "brute force" computing. You will learn in more advanced computer science courses that there are large numbers of interesting problems for which there is no known algorithmic approach other than using sheer brute force.

5.18 Modify Exercise 5.10 to combine your code from the four separate triangles of asterisks into a single application that prints all four patterns side by side, making clever use of nested **for** loops.

```
*           **********  **********          *
**          *********    *********         **
***         ********      ********        ***
****        *******        *******       ****
*****       ******          ******      *****
******      *****            *****     ******
*******     ****              ****    *******
********    ***                ***   ********
*********   *                   **  *********
**********  *                     * **********
```

5.19 (*De Morgan's Laws*) In this chapter, we have discussed the logical operators **&&**, **&**, **||**, **|**, **^** and **!**. De Morgan's Laws can sometimes make it more convenient for us to express a logical expression. These laws state that the expression **!(***condition1* **&&** *condition2***)** is logically equivalent to the expression **(!***condition1* **||** **!***condition2***)**. Also, the expression **!(***condition1* **||** *condition2***)** is logically equivalent to the expression **(!***condition1* **&& !***condition2***)**. Use De Morgan's Laws to write equivalent expressions for each of the following, and then write a program to show that both the original expression and the new expression in each case are equivalent:

a) `!( x < 5 ) && !( y >= 7 )`
b) `!( a == b ) || !( g != 5 )`
c) `!( ( x <= 8 ) && ( y > 4 ) )`
d) `!( ( i > 4 ) || ( j <= 6 ) )`

5.20 Write an application that prints the following diamond shape. You may use output statements that print a single asterisk (*****), a single space or a single newline character. Maximize your use of repetition (with nested **for** structures,) and minimize the number of output statements.

```
    *
   ***
  *****
 *******
*********
 *******
  *****
   ***
    *
```

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5.21 Modify the program you wrote in Exercise 5.20 to read an odd number in the range 1 to 19 to specify the number of rows in the diamond. Your program should then display a diamond of the appropriate size.

5.22 A criticism of the **break** statement and the **continue** statement is that each is unstructured. Actually, **break** statements and **continue** statements can always be replaced by structured statements, although doing so can be awkward. Describe in general how you would remove any **break** statement from a loop in a program and replace that statement with some structured equivalent. [*Hint*: The **break** statement leaves a loop from within the body of the loop. The other way to leave is by failing the loop-continuation test. Consider using in the loop-continuation test a second test that indicates "early exit because of a 'break' condition."] Use the technique you developed here to remove the **break** statement from the program in Fig. 5.11.

5.23 What does the following program segment do?

```
for ( i = 1; i <= 5; i++ ) {

   for ( j = 1; j <= 3; j++ ) {

      for ( k = 1; k <= 4; k++ )
         System.out.print( '*' );

      System.out.println();
   }

   System.out.println();
}
```

5.24 Describe in general how you would remove any **continue** statement from a loop in a program and replace that statement with some structured equivalent. Use the technique you developed here to remove the **continue** statement from the program in Fig. 5.12.

5.25 (*"The Twelve Days of Christmas" Song*) Write an application that uses repetition and **switch** structures to print the song "The Twelve Days of Christmas." One **switch** structure should be used to print the day (i.e., "First," "Second," etc.). A separate **switch** structure should be used to print the remainder of each verse. Visit the Web site **www.12days.com/library/carols/12daysofxmas.htm** for the complete lyrics to the song.

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6

Methods

Objectives

- To understand how to construct programs modularly from small pieces called *methods*.
- To introduce the common math methods available in the Java API.
- To be able to create new methods.
- To understand the mechanisms for passing information between methods.
- To introduce simulation techniques that use random-number generation.
- To understand how the visibility of identifiers is limited to specific regions of programs.
- To understand how to write and use methods that call themselves.

Form ever follows function.
Louis Henri Sullivan

E pluribus unum.
(One composed of many.)
Virgil

O! call back yesterday, bid time return.
William Shakespeare, *Richard II*

Call me Ishmael.
Herman Melville, *Moby Dick*

When you call me that, smile.
Owen Wister

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Outline

6.1 Introduction
6.2 Program Modules in Java
6.3 `Math` Class Methods
6.4 Methods
6.5 Method Definitions
6.6 Argument Promotion
6.7 Java API Packages
6.8 Random-Number Generation
6.9 Example: A Game of Chance
6.10 Duration of Identifiers
6.11 Scope Rules
6.12 Recursion
6.13 Example Using Recursion: The Fibonacci Series
6.14 Recursion vs. Iteration
6.15 Method Overloading
6.16 Methods of Class `JApplet`
6.17 (Optional Case Study) Thinking About Objects: Identifying Class Operations

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

6.1 Introduction

Most computer programs that solve real-world problems are much larger than the programs presented in the first few chapters of this text. Experience has shown that the best way to develop and maintain a large program is to construct it from small, simple pieces, or *modules*. This technique is called *divide and conquer*. This chapter describes many key features of the Java language that facilitate the design, implementation, operation and maintenance of large programs.

6.2 Program Modules in Java

Modules in Java are called *methods* and *classes*. Java programs are written by combining new methods and classes the programmer writes with "prepackaged" methods and classes available in the *Java API* (also referred to as the *Java class library*) and in various other method and class libraries. In this chapter, we concentrate on methods; we begin to discuss classes in detail in Chapter 8.

The Java API provides a rich collection of classes and methods for performing common mathematical calculations, string manipulations, character manipulations, input/output operations, error checking and many other useful operations. This set of modules makes the programmer's job easier, because the modules provide many of the capabilities

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programmers need. The Java API methods are provided as part of the Java 2 Software Development Kit (J2SDK).

Good Programming Practice 6.1

Familiarize yourself with the rich collection of classes and methods in the Java API and with the rich collections of classes available in various class libraries.

Software Engineering Observation 6.1

Avoid reinventing the wheel. When possible, use Java API classes and methods instead of writing new classes and methods. This reduces program development time and avoids introducing programming errors.

Performance Tip 6.1

Do not try to rewrite existing Java API classes and methods to make them more efficient. You usually will not be able to increase the performance of these classes and methods.

The programmer can write methods to define specific tasks that a program may use many times during its execution. These are sometimes referred to as *programmer-defined methods.* The actual statements defining the methods are written only once and are hidden from other methods.

A method is *invoked* (i.e., made to perform its designated task) by a *method call.* The method call specifies the name of the method and provides information (as *arguments*) that the called method requires to perform its task. When the method call completes, the method either returns a result to the *calling method* (or *caller*) or simply returns control to the calling method. A common analogy for this program structure is the hierarchical form of management. A boss (the calling method, or caller) asks a worker (the *called method*) to perform a task and report back (i.e., *return*) the results after completing the task. The boss method does not know *how* the worker method performs its designated tasks. The worker may also call other worker methods, and the boss will be unaware of this occurrence. We will soon see how this "hiding" of implementation details promotes good software engineering. Figure 6.1 shows the **`boss`** method communicating with several worker methods in a hierarchical manner. Note that **`worker1`** acts as a "boss method" to **`worker4`** and **`worker5`**. Relationships among methods may also be different than the hierarchical structure shown in this figure.

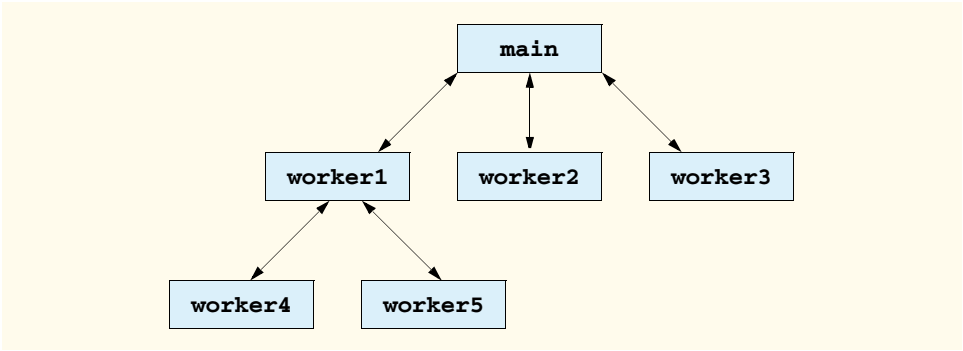

Fig. 6.1 Hierarchical boss-method/worker-method relationship.

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6.3 `Math` Class Methods

`Math` class methods allow the programmer to perform certain common mathematical calculations. We use various **`Math`** class methods here to introduce the concept of methods. Throughout the book, we discuss many other methods from the classes of the Java API.

Methods are called by writing the name of the method, followed by a left parenthesis, followed by the *argument* (or a comma-separated list of arguments) of the method, followed by a right parenthesis. For example, a programmer desiring to calculate the square root of **`900.0`** might write

```
Math.sqrt( 900.0 )
```

When this statement executes, it calls **`static`** **`Math`** method **`sqrt`** to calculate the square root of the number contained in the parentheses (**`900.0`**). The number **`900.0`** is the *argument* of method **`sqrt`**. The preceding expression evaluates to **`30.0`**. Method **`sqrt`** method takes an argument of type **`double`** and returns a result of type **`double`**. Note that all **`Math`** class methods are **`static`**; therefore, they are invoked by preceding the name of the method with the class name **`Math`** and a dot (**`.`**) operator. To output the value of the preceding method call in the command window, a programmer might write

```
System.out.println( Math.sqrt( 900.0 ) );
```

In this statement, the value that **`sqrt`** returns becomes the argument to method **`println`**.

Software Engineering Observation 6.2

*It is not necessary to import class **`Math`** to use its methods. **`Math`** is part of the **`java.lang`** package, which is automatically imported by the compiler.*

Common Programming Error 6.1

*Forgetting to invoke a **`Math`** class method by preceding the name of the method with the class name **`Math`** and a dot operator (**`.`**) results in a syntax error.*

Method arguments may be constants, variables or expressions. If **`c1 = 13.0`**, **`d = 3.0`** and **`f = 4.0`**, then the statement

```
System.out.println( Math.sqrt( c1 + d * f ) );
```

calculates and prints the square root of **`13.0 + 3.0 * 4.0 = 25.0`**, namely **`5.0`**.

Some **`Math`** class methods are summarized in Fig. 6.2. In the figure, the variables **`x`** and **`y`** are of type **`double`**. The **`Math`** class also defines two commonly used mathematical constants: **`Math.PI`** and **`Math.E`**. The constant **`Math.PI`** (3.14159265358979323846) of class **`Math`** is the ratio of a circle's circumference to its diameter. The constant **`Math.E`** (2.7182818284590452354) is the base value for natural logarithms (calculated with static **`Math`** method **`log`**).

6.4 Methods

Methods allow the programmer to modularize a program. Variables declared in method definitions are *local variables*—only the method that defines them knows they exist. Most methods have a list of *parameters* that provide the means for communicating information between methods via method calls. A method's parameters are also local variables.

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Method	Description	Example

`abs( x )`	absolute value of *x*
	(this method also has versions for `float`, `int` and `long` values)
		`abs( 23.7 )` is `23.7`
		`abs( 0.0 )` is `0.0`
		`abs( -23.7 )` is `23.7`

`ceil( x )`	rounds *x* to the smallest integer not less than *x*	`ceil( 9.2 )` is `10.0` `ceil( -9.8 )` is `-9.0`
`cos( x )`	trigonometric cosine of *x* (*x* is in radians)	`cos( 0.0 )` is `1.0`
`exp( x )`	exponential method e^x	`exp( 1.0 )` is `2.71828` `exp( 2.0 )` is `7.38906`
`floor( x )`	rounds *x* to the largest integer not greater than *x*	`floor( 9.2 )` is `9.0` `floor( -9.8 )` is `-10.0`
`log( x )`	natural logarithm of *x* (base *e*)	`log( 2.718282 )` is `1.0` `log( 7.389056 )` is `2.0`
`max( x, y )`	larger value of *x* and *y* (this method also has versions for `float`, `int` and `long` values)	`max( 2.3, 12.7 )` is `12.7` `max( -2.3, -12.7 )` is `-2.3`
`min( x, y )`	smaller value of *x* and *y* (this method also has versions for `float`, `int` and `long` values)	`min( 2.3, 12.7 )` is `2.3` `min( -2.3, -12.7 )` is `-12.7`
`pow( x, y )`	*x* raised to power *y* (x^y)	`pow( 2.0, 7.0 )` is `128.0` `pow( 9.0, .5 )` is `3.0`
`sin( x )`	trigonometric sine of *x* (*x* is in radians)	`sin( 0.0 )` is `0.0`
`sqrt( x )`	square root of *x*	`sqrt( 900.0 )` is `30.0` `sqrt( 9.0 )` is `3.0`
`tan( x )`	trigonometric tangent of *x* (*x* is in radians)	`tan( 0.0 )` is `0.0`

Fig. 6.2 **`Math`** class methods.

There are several motivations for modularizing a program with methods. The divide-and-conquer approach makes program development more manageable. Another motivation is *software reusability*—using existing methods as building blocks to create new programs. With good method naming and definition, you can create programs from standardized methods rather than by building customized code. For example, we did not have to define how to convert **`String`**s to integers and floating-point numbers; Java already provides such methods for us in class **`Integer`** (**`parseInt`**) and class **`Double`** (**`parseDouble`**). A third motivation is to avoid repeating code in a program. Packaging code as a method allows a program to execute that code from several locations in a program simply by calling the method.

Software Engineering Observation 6.3

To promote software reusability, each method should be limited to performing a single, well-defined task, and the name of the method should express that task effectively.

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Software Engineering Observation 6.4

If you cannot choose a concise name that expresses a method's task, it is possible that your method is attempting to perform too many diverse tasks. It is usually best to break such a method into several smaller method definitions.

6.5 Method Definitions

The programs presented up to this point each consisted of a class definition containing at least one method definition that called Java API methods to accomplish its tasks. We now consider how programmers write their own customized methods. Until we discuss more of the details of class definitions in Chapter 8, we use applets for all programs that contain two or more method definitions, for simplicity.

Consider an applet that uses a method **square** (invoked from the applet's **init** method) to calculate the squares of the integers from 1 to 10 (Fig. 6.3).

When the applet begins execution, the applet container calls the applet's **init** method. Line 16 declares **JTextArea** reference **outputArea** and initializes it with a new **JTextArea**. This **JTextArea** will display the program's results.

This program is the first in which we display a GUI component on an applet. The on-screen display area for a **JApplet** has a *content pane*, to which the GUI components must be attached so they can be displayed at execution time. The content pane is an object of class ***Container*** from the ***java.awt*** *package*. This class was **import**ed on line 5 for use in the applet. Line 19 declares **Container** reference **container** and assigns to it the result of a call to method ***getContentPane***—one of the many methods that our class **SquareInt** inherits from class **JApplet**. Method **getContentPane** returns a reference to the applet's content pane. The program uses that reference to attach GUI components, like a **JTextArea**, to the applet's user interface.

Line 22 places the **JTextArea** GUI component object to which **outputArea** refers on the applet. When the applet executes, any GUI components attached to it are displayed. **Container** method **add** attaches a GUI component to a container. For the moment, we can attach only one GUI component to the applet's content pane, and that GUI component will occupy the applet's entire drawing area on the screen (as defined by the **width** and **height** of the applet, in pixels, in the applet's HTML document). Later, we will discuss how to attach many GUI components to an applet by changing the applet's *layout*. The layout controls how the applet positions GUI components in its area on the screen.

Line 24 declares **int** variable **result** to store the result of each square calculation. Line 25 declares **String** reference **output** and initializes it with the empty string. This **String** will contain the results of squaring the values from 1 to 10. Lines 28–37 define a **for** repetition structure. Each iteration of this loop calculates the **square** of the current value of control variable **x**, stores the value in **result** and concatenates the **result** to the end of **output**.

The applet invokes (or calls) its **square** method on line 31 with the statement

```
result = square( counter );
```

The **()** after **square** represent the *method-call operator*, which has high precedence. At this point, the program makes a copy of the value of **counter** (the *argument* to the method call) and transfers program control to the first line of method **square** (defined at lines 44–

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48). Method **square** receives the copy of the value of **counter** in the *parameter* **y**. Then, **square** calculates **y * y** (line 46). Method **square** uses a ***return*** statement to return (i.e., give back) the result of the calculation to the statement in **init** that invoked **square**. In method **init**, the return value is assigned to variable **result**. Lines 34–35 concatenate **"The square of "**, the value of **counter**, **" is "**, the value of **result** and a newline character to the end of **output**. This process repeats for each iteration of the **for** repetition structure. Line 39 uses method **setText** to set **outputArea**'s text to the **String output**.

```
1  // Fig. 6.3: SquareIntegers.java
2  // A programmer-defined square method
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class SquareIntegers extends JApplet {
11
12    // set up GUI and calculate squares of integers from 1 to 10
13    public void init()
14    {
15       // JTextArea to display results
16       JTextArea outputArea = new JTextArea();
17
18       // get applet's content pane (GUI component display area)
19       Container container = getContentPane();
20
21       // attach outputArea to container
22       container.add( outputArea );
23
24       int result;  // store result of call to method square
25       String output = "";  // String containing results
26
27       // loop 10 times
28       for ( int counter = 1; counter <= 10; counter++ ) {
29
30          // calculate square of counter and store in result
31          result = square( counter );
32
33          // append result to String output
34          output += "The square of " + counter +
35                    " is " + result + "\n";
36
37       }  // end for structure
38
39       outputArea.setText( output );  // place results in JTextArea
40
41    }  // end method init
42
```

Fig. 6.3 Using programmer-defined method **square** (part 1 of 2).

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```
43      // square method definition
44      public int square( int y )
45      {
46         return y * y;  // return square of y
47
48      }  // end method square
49
50   }  // end class SquareIntegers
```

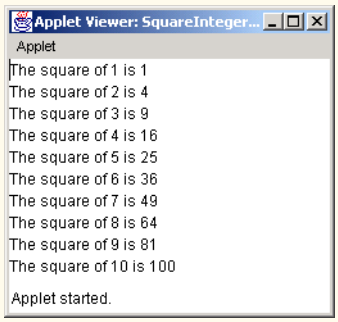

Fig. 6.3 Using programmer-defined method **square** (part 2 of 2).

Note that we declared references **output**, **outputArea** and **container** and variable **result** as local variables in **init**, because they are used only in **init**. Variables should be declared as instance variables only if they are required for use in more than one method of the class or if the program should save their values between calls to the class's methods. Also, note that method **init** calls method **square** directly without preceding the method name with a class name and a dot operator or a reference name and a dot operator. Each method in a class is able to call the class's other methods directly. However, there is an exception to this rule. A class's **static** methods can call only other **static** methods of the class directly. Chapter 8 discusses **static** methods in detail.

The definition of method **square** (line 44) shows that **square** expects an integer parameter **y**; **square** uses this name to manipulate the value it receives. Keyword **int** preceding the name of the method indicates that **square** returns an integer result. The **return** statement in **square** passes the result of the calculation **y * y** back to the calling method. Note that the entire method definition appears between the braces of the class **SquareInt**. All methods must be defined inside a class definition.

Good Programming Practice 6.2

Place a blank line between method definitions to separate the methods and enhance program readability.

Common Programming Error 6.2

Defining a method outside the braces of a class definition is a syntax error.

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The general format of a method definition is

```
return-value-type  method-name ( parameter-list )
{
    declarations and statements
}
```

The *method-name* is any valid identifier. The *return-value-type* is the data type of the result returned from the method to the caller. The *return-value-type* **void** indicates that a method does not return a value. Methods can return at most one value.

The *parameter-list* is a comma-separated list in which the method declares each parameter's type and name. There must be one argument in the method call for each parameter in the method definition. Each argument also must be compatible with the type of the corresponding parameter in the method definition. For example, a parameter of type **double** can receive values of 7.35, 22 or –0.03546, but not **"hello"** (because a **String** cannot be assigned to a **double** variable). If a method does not receive any values, the *parameter-list* is empty (i.e., the name of the method is followed by an empty set of parentheses). Each parameter in the parameter list of a method must be declared with a data type; otherwise, a syntax error occurs.

Following the first line of the method definition (also known as the *method header*), *declarations and statements* in braces form the *method body*. The method body is also referred to as a block. Variables can be declared in any block, and blocks can be nested. A method cannot be defined inside another method.

There are three ways to return control to the statement that invoked a method. If the method does not return a result, control returns when the program flow reaches the method-ending right brace or when the statement

```
return;
```

is executed. If the method returns a result, the statement

```
return expression;
```

evaluates the *expression*, then returns the resulting value to the caller. When a **return** statement executes, control returns immediately to the statement that invoked the method.

Note that the example in Fig. 6.3 actually contains two method definitions—**init** (lines 13–41) and **square** (line 44–48). Remember that the applet container calls method **init** to initialize the applet. In this example, method **init** repeatedly invokes the **square** method to perform a calculation, then places the results in the **JTextArea** that is attached to the applet's content pane. When the applet appears on the screen, the results are displayed in the **JTextArea**.

Notice the syntax used to invoke method **square**—we use just the name of the method, followed by the arguments to the method in parentheses. Methods in a class definition are allowed to invoke other methods in the same class definition by using this syntax. (There is an exception to this rule, discussed in Chapter 8.) Methods in the same class definition are both the methods defined in that class and the inherited methods (the methods from the class that the current class **extends**—**JApplet** in Fig. 6.3). We have now seen three ways to call a method: A method name by itself (as shown with **square(x)** in this example), a reference to an object followed by the dot (**.**) operator and the method name

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(such as **`g.drawLine( x1, y1, x2, y2 )`**), and a class name followed by a method name (such as **`Integer.parseInt( stringToConvert )`**). The last syntax is only for **`static`** methods of a class (discussed in detail in Chapter 8).

Common Programming Error 6.3

Omitting the return-value-type *in a method definition is a syntax error.*

Common Programming Error 6.4

Forgetting to return a value from a method that should return a value is a syntax error. If a return value type other than **`void`** *is specified, the method must contain a* **`return`** *statement.*

Common Programming Error 6.5

Returning a value from a method whose return type has been declared **`void`** *is a syntax error.*

Common Programming Error 6.6

Declaring method parameters of the same type as **`float x, y`** *instead of* **`float x, float y`** *is a syntax error, because types are required for each parameter in the parameter list.*

Common Programming Error 6.7

Placing a semicolon after the right parenthesis enclosing the parameter list of a method definition is a syntax error.

Common Programming Error 6.8

Redefining a method parameter in the method's body is a syntax error.

Common Programming Error 6.9

Passing to a method an argument that is not compatible with the corresponding parameter's type is a syntax error.

Common Programming Error 6.10

Defining a method inside another method is a syntax error.

Good Programming Practice 6.3

Avoid using the same names for instance variables and local variables. This helps readers of your program distinguish variables used in different parts of a class definition.

Good Programming Practice 6.4

Choosing meaningful method names and meaningful parameter names makes programs more readable and helps avoid excessive use of comments.

Software Engineering Observation 6.5

A method should usually be no longer than one page. Better yet, a method should usually be no longer than half a page. Regardless of how long a method is, it should perform one task well. Small methods promote software reusability.

Software Engineering Observation 6.6

Programs should be written as collections of small methods. This makes programs easier to write, debug, maintain and modify.

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Software Engineering Observation 6.7

A method requiring a large number of parameters may be performing too many tasks. Consider dividing the method into smaller methods that perform the separate tasks. The method header should fit on one line if possible.

Software Engineering Observation 6.8

The method header and method calls must all agree in the number, type and order of parameters and arguments.

Testing and Debugging Tip 6.1

Small methods are easier to test, debug and understand than large ones.

The applet in our next example (Fig. 6.4) uses a programmer-defined method called **maximum** to determine and return the largest of three floating-point values.

```
1  // Fig. 6.4: Maximum.java
2  // Finding the maximum of three doubles
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class Maximum extends JApplet {
11
12    // initialize applet by obtaining user input and creating GUI
13    public void init()
14    {
15       // obtain user input
16       String s1 = JOptionPane.showInputDialog(
17          "Enter first floating-point value" );
18       String s2 = JOptionPane.showInputDialog(
19          "Enter second floating-point value" );
20       String s3 = JOptionPane.showInputDialog(
21          "Enter third floating-point value" );
22
23       // convert user input to double values
24       double number1 = Double.parseDouble( s1 );
25       double number2 = Double.parseDouble( s2 );
26       double number3 = Double.parseDouble( s3 );
27
28       // call method maximum to determine largest value
29       double max = maximum( number1, number2, number3 );
30
31       // create JTextArea to display results
32       JTextArea outputArea = new JTextArea();
33
```

Fig. 6.4 Programmer-defined **maximum** method (part 1 of 2).

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```
34          // display numbers and maximum value
35          outputArea.setText( "number1: " + number1 +
36             "\nnumber2: " + number2 + "\nnumber3: " + number3 +
37             "\nmaximum is: " + max );
38
39          // get the applet's GUI component display area
40          Container container = getContentPane();
41
42          // attach outputArea to Container c
43          container.add( outputArea );
44
45       }  // end method init
46
47       // maximum method uses Math class method max to help
48       // determine maximum value
49       public double maximum( double x, double y, double z )
50       {
51          return Math.max( x, Math.max( y, z ) );
52
53       }  // end method maximum
54
55    }  // end class Maximum
```

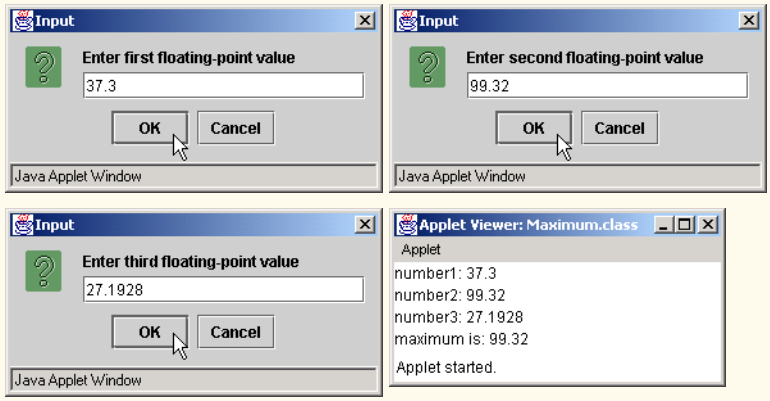

Fig. 6.4 Programmer-defined **maximum** method (part 2 of 2).

The three floating-point values are input by the user via input dialogs (lines 16–21 of **init**). Lines 24–26 use method **Double.parseDouble** to convert the **String**s input by the user to **double** values. Line 29 calls method **maximum** (defined on lines 49–53) to determine the largest **double** value of the three **double** values passed as arguments to the method. Method **maximum** returns the result to method **init**, using a **return** statement. The program assigns the result to variable **max**. Lines 35–37 use **String** concatenation to form a **String** containing the three **double** values input by the user and the **max** value and place the result in **JTextArea outputArea**.

Notice the implementation of the method **maximum** (lines 49–53). The first line indicates that the method returns a **double** floating-point value, that the method's name is **maximum** and that the method takes three **double** parameters (**x**, **y** and **z**) to accomplish its task. Also, the statement (line 51) in the body of the method returns the largest of the

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three floating-point values, using two calls to the **Math.max** method. First, the statement invokes method **Math.max** with the values of variables **y** and **z** to determine the larger of the two values. Next, the statement passes the value of variable **x** and the result of the first call to **Math.max** to method **Math.max**. Finally, the statement returns the result of the second call to **Math.max** to line 29 (the point at which method **init** invoked method **maximum**).

6.6 Argument Promotion

Another important feature of method definitions is the *coercion of arguments* (i.e., the forcing of arguments to the appropriate type to pass to a method). For example, a program can call **Math** method **sqrt** with an integer argument even though the method expects to receive a **double** argument. For example, the statement

```
System.out.println( Math.sqrt( 4 ) );
```

correctly evaluates **Math.sqrt(4)** and prints the value **2**. The method definition's parameter list causes Java to convert the integer value **4** to the **double** value **4.0** before passing the value to **sqrt**. In some cases, attempting these conversions leads to compiler errors if Java's *promotion rules* are not satisfied. The promotion rules specify how to convert types to other types without losing data. In our **sqrt** example above, an **int** is converted to a **double** without changing its value. However, converting a **double** to an **int** truncates the fractional part of the **double** value. Converting large integer types to small integer types (e.g., **long** to **int**) may also result in changed values.

The promotion rules apply to expressions containing values of two or more data types (also referred to as *mixed-type expressions*) and to primitive-data-type values passed as arguments to methods. The type of each value in a mixed-type expression is promoted to the "highest" type in the expression (actually, the expression uses a temporary copy of each value; the original values remain unchanged). The type of a method argument can be promoted to any "higher" type. Figure 6.5 lists the primitive data types and the types to which each is allowed to be promoted automatically.

Type	Allowed promotions
double	None
float	**double**
long	**float** or **double**
int	**long**, **float** or **double**
char	**int**, **long**, **float** or **double**
short	**int**, **long**, **float** or **double**
byte	**short**, **int**, **long**, **float** or **double**
boolean	None (**boolean** values are not considered to be numbers in Java)

Fig. 6.5 Allowed promotions for primitive data types.

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Converting values to lower types can result in different values. Therefore, in cases where information may be lost due to conversion, the Java compiler requires the programmer to use a cast operator to force the conversion to occur. To invoke our **square** method, which uses an integer parameter with the **double** variable **y** (Fig. 6.3), we write the method call as **square((int) y)**. This method call explicitly casts (converts) the value of **y** to an integer for use in method **square**. Thus, if **y**'s value is **4.5**, method **square** returns **16**, not **20.25**.

Common Programming Error 6.11

*Converting a primitive-data-type value to another primitive data type may change the value if the new data type is not an allowed promotion (e.g., **double** to **int**). Also, converting any integral value to a floating-point value and back to an integral value may introduce rounding errors into the result.*

6.7 Java API Packages

As we have seen, Java contains many predefined classes that are grouped into categories of related classes, called *packages*. Together, we refer to these packages as the *Java applications programming interface* (*Java API*), or the *Java class library*.

Throughout the text, **import** statements specify the classes required to compile a Java program. For example, a program uses the statement

```
import javax.swing.JApplet;
```

to tell the compiler to load the **JApplet** class from the **javax.swing** package. One of the great strengths of Java is the large number of classes in the packages of the Java API that programmers can reuse rather than "reinventing the wheel." We exercise a large number of these classes in this book. Figure 6.6 lists a subset of the many packages in the Java API and provides a brief description of each package. We use classes from these packages and others throughout this book. We provide this table to begin introducing you the variety of reusable components available in the Java API. When learning Java, you should spend time reading the descriptions of the packages and classes in the Java API documentation (**java.sun.com/j2se/1.3/docs/api**).

Package	Description
java.applet	*The Java Applet Package.* This package contains the **Applet** class and several interfaces that enable the creation of applets, interaction of applets with the browser and playing audio clips. In Java 2, class **javax.swing.JApplet** is used to define an applet that uses the *Swing GUI components*.
java.awt	*The Java Abstract Windowing Toolkit Package.* This package contains the classes and interfaces required to create and manipulate graphical user interfaces in Java 1.0 and 1.1. In Java 2, these classes can still be used, but the *Swing GUI components* of the **javax.swing** packages are often used instead.

Fig. 6.6 Packages of the Java API (part 1 of 2).

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Package	Description
java.awt.event	*The Java Abstract Windowing Toolkit Event Package.* This package contains classes and interfaces that enable event handling for GUI components in both the **java.awt** and **javax.swing** packages.
java.io	*The Java Input/Output Package.* This package contains classes that enable programs to input and output data (see Chapter 16, Files and Streams).
java.lang	*The Java Language Package.* This package contains classes and interfaces required by many Java programs (many are discussed throughout this text) and is automatically imported by the compiler into all programs.
java.net	*The Java Networking Package.* This package contains classes that enable programs to communicate via networks (see Chapter 17, Networking).
java.text	*The Java Text Package.* This package contains classes and interfaces that enable a Java program to manipulate numbers, dates, characters and strings. It provides many of Java's internationalization capabilities i.e., features that enable a program to be customized to a specific locale (e.g., an applet may display strings in different languages, based on the user's country).
java.util	*The Java Utilities Package.* This package contains utility classes and interfaces, such as: date and time manipulations, random-number processing capabilities (**Random**), storing and processing large amounts of data, breaking strings into smaller pieces called *tokens* (**StringTokenizer**) and other capabilities (see Chapter 19, Data Structures, Chapter 20, Java Utilities Package and Bit Manipulation, and Chapter 21, The Collections API).
javax.swing	*The Java Swing GUI Components Package.* This package contains classes and interfaces for Java's Swing GUI components that provide support for portable GUIs.
javax.swing.event	*The Java Swing Event Package.* This package contains classes and interfaces that enable event handling for GUI components in the **javax.swing** package.

Fig. 6.6 Packages of the Java API (part 2 of 2).

The set of packages available in the Java 2 Software Development Kit (J2SDK) is quite large. In addition to the packages summarized in Fig. 6.6, the J2SDK includes packages for complex graphics, advanced graphical user interfaces, printing, advanced networking, security, database processing, multimedia, accessibility (for people with disabilities) and many other functions. For an overview of the packages in the J2SDK version 1.3, visit

java.sun.com/j2se/1.3/docs/api/overview-summary.html

Also, many other packages are available for download at **java.sun.com**.

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6.8 Random-Number Generation

We now take a brief and, hopefully, entertaining diversion into a popular programming application, namely, simulation and game playing. In this section and the next section, we will develop a nicely structured game-playing program that includes multiple methods. The program uses most of the control structures we have studied to this point in the book and introduces several new concepts.

There is something in the air of a gambling casino that invigorates people—from the high rollers at the plush mahogany-and-felt craps tables to the quarter poppers at the one-armed bandits. It is the *element of chance*, the possibility that luck will convert a pocketful of money into a mountain of wealth. The element of chance can be introduced through the **random** method from the **Math** class. [Note: Java also provides a **Random** class in package java.util. Class **Random** is covered in Chapter 20.]

Consider the following statement:

```
double randomValue = Math.random();
```

The **random** method of class **Math** generates a random **double** value from 0.0 up to, but not including, 1.0. If method **random** truly produces values at random, then every value from 0.0 up to, but not including, 1.0 should have an equal *chance* (or *probability*) of being chosen each time method **random** is called. Note that the values returned by **random** are actually *pseudo-random numbers*—a sequence of values produced by a complex mathematical calculation. That calculation uses the current time of day to *seed* the random number generator, such that each execution of a program yields a different sequence of random values.

The range of values produced directly by method **random** often is different from the range of values required in a particular Java application. For example, a program that simulates coin tossing might require only 0 for "heads" and 1 for "tails." A program that simulates rolling a six-sided die would require random integers in the range from 1 to 6. A program that randomly predicts the next type of spaceship (out of four possibilities) that will fly across the horizon in a video game would require random integers in the range from 1 to 4.

To demonstrate method **random**, let us develop a program that simulates 20 rolls of a six-sided die and displays the value of each roll. We use the multiplication operator (*****) in conjunction with method **random** as follows to produce integers in the range from 0 to 5:

```
(int) ( Math.random() * 6 )
```

This manipulation is called *scaling* the range of values produced by **Math** method **random**. The number **6** in the preceding expression is called the *scaling factor*. The integer cast operator truncates the floating-point part (the part after the decimal point) of each value produced by the expression. Next, we *shift* the range of numbers produced by adding 1 to our previous result, as in

```
1 + (int) ( Math.random() * 6 )
```

Figure 6.7 confirms that the results of the preceding calculation are integers in the range from 1 to 6.

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```
1  // Fig. 6.7: RandomIntegers.java
2  // Shifted, scaled random integers.
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class RandomIntegers {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int value;
13       String output = "";
14
15       // loop 20 times
16       for ( int counter = 1; counter <= 20; counter++ ) {
17
18          // pick random integer between 1 and 6
19          value = 1 + ( int ) ( Math.random() * 6 );
20
21          output += value + "   ";  // append value to output
22
23          // if counter divisible by 5,
24          // append newline to String output
25          if ( counter % 5 == 0 )
26             output += "\n";
27
28       }  // end for structure
29
30       JOptionPane.showMessageDialog( null, output,
31          "20 Random Numbers from 1 to 6",
32          JOptionPane.INFORMATION_MESSAGE );
33
34       System.exit( 0 );  // terminate application
35
36    }  // end method main
37
38 }  // end class RandomIntegers
```

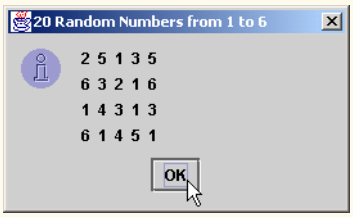

Fig. 6.7 Shifted and scaled random integers .

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To show that these numbers occur with approximately equal likelihood, let us simulate 6000 rolls of a die with the program in Fig. 6.8. Each integer from 1 to 6 should appear approximately 1000 times.

```
1  // Fig. 6.8: RollDie.java
2  // Roll a six-sided die 6000 times.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class RollDie {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int frequency1 = 0, frequency2 = 0, frequency3 = 0,
13           frequency4 = 0, frequency5 = 0, frequency6 = 0, face;
14
15       // summarize results
16       for ( int roll = 1; roll <= 6000; roll++ ) {
17          face = 1 + ( int ) ( Math.random() * 6 );
18
19          // determine roll value and increment appropriate counter
20          switch ( face ) {
21
22             case 1:
23                ++frequency1;
24                break;
25
26             case 2:
27                ++frequency2;
28                break;
29
30             case 3:
31                ++frequency3;
32                break;
33
34             case 4:
35                ++frequency4;
36                break;
37
38             case 5:
39                ++frequency5;
40                break;
41
42             case 6:
43                ++frequency6;
44                break;
45
46          }  // end switch structure
47
48       }  // end for structure
```

Fig. 6.8 Rolling a six-sided die 6000 times (part 1 of 2).

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```
49
50          JTextArea outputArea = new JTextArea();
51
52          outputArea.setText( "Face\tFrequency" +
53             "\n1\t" + frequency1 + "\n2\t" + frequency2 +
54             "\n3\t" + frequency3 + "\n4\t" + frequency4 +
55             "\n5\t" + frequency5 + "\n6\t" + frequency6 );
56
57          JOptionPane.showMessageDialog( null, outputArea,
58             "Rolling a Die 6000 Times",
59             JOptionPane.INFORMATION_MESSAGE );
60
61          System.exit( 0 );  // terminate application
62
63       }  // end method main
64
65    }  // end class RollDie
```

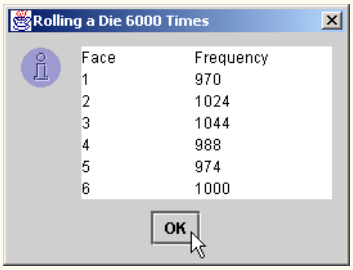

Fig. 6.8 Rolling a six-sided die 6000 times (part 2 of 2).

As the program output shows, scaling and shifting the values produced by method **random** enables the program to simulate realistically the rolling of a six-sided die. Note that the use of nested control structures in the program to determine the number of times each side of the six-sided die occurred. The **for** structure at lines 16–48 iterates 6000 times. During each iteration of the loop, line 17 produces a value from 1 to 6. The nested **switch** structure at lines 20–46 uses as its controlling expression the **face** value that was randomly chosen. Based on the value of **face**, the **switch** structure increments one of the six counter variables during each iteration of the loop. Note that the **switch** structure has no **default** case. When we study arrays in Chapter 7, we show how to replace the entire **switch** structure in this program with a single statement. Run the program several times, and observe the results. Notice that the program produces different results each time the program executes.

The values produced directly by **random** are always in the range

$$0.0 \leq \texttt{Math.random()} < 1.0$$

Previously, we demonstrated how to write a single statement to simulate the rolling of a six-sided die with the statement

```
face = 1 + (int) ( Math.random() * 6 );
```

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which always assigns an integer (at random) to variable **face** in the range $1 \leq$ **face** ≤ 6. Note that the width of this range (i.e., the number of consecutive integers in the range) is 6, and the starting number in the range is 1. Referring to the preceding statement, we see that the width of the range is determined by the number used to scale **random** with the multiplication operator (i.e., 6), and the starting number of the range is equal to the number (i.e., 1) added to **(int) (Math.random() * 6)**. We can generalize this result as

```
n = a + (int) ( Math.random() * b );
```

where **a** is the *shifting value* (which is equal to the first number in the desired range of consecutive integers) and **b** is the *scaling factor* (which is equal to the width of the desired range of consecutive integers). In the exercises, we will see that it is possible to choose integers at random from sets of values other than ranges of consecutive integers.

6.9 Example: A Game of Chance

One of the most popular games of chance is a dice game known as "craps," which is played in casinos and back alleys throughout the world. The rules of the game are straightforward:

> *A player rolls two dice. Each die has six faces. These faces contain one, two, three, four, five and six spots, respectively. After the dice have come to rest, the sum of the spots on the two upward faces is calculated. If the sum is 7 or 11 on the first throw, the player wins. If the sum is 2, 3 or 12 on the first throw (called "craps"), the player loses (i.e., the "house" wins). If the sum is 4, 5, 6, 8, 9 or 10 on the first throw, that sum becomes the player's "point." To win, you must continue rolling the dice until you "make your point" (i.e., roll your point value). The player loses by rolling a 7 before making the point.*

The applet in Fig. 6.9 simulates the game of craps.

```
1  // Fig. 6.9: Craps.java
2  // Craps
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class Craps extends JApplet implements ActionListener {
12
13    // constant variables for game status
14    final int WON = 0, LOST = 1, CONTINUE = 2;
15
16    // other variables used
17    boolean firstRoll = true;   // true if first roll of dice
18    int sumOfDice = 0;          // sum of the dice
19    int myPoint = 0;    // point if no win/loss on first roll
20    int gameStatus = CONTINUE;  // game not over yet
21
```

Fig. 6.9 Program to simulate the game of craps (part 1 of 5).

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```
22     // graphical user interface components
23     JLabel die1Label, die2Label, sumLabel, pointLabel;
24     JTextField die1Field, die2Field, sumField, pointField;
25     JButton rollButton;
26
27     // set up GUI components
28     public void init()
29     {
30        // obtain content pane and change its layout to
31        // a FlowLayout
32        Container container = getContentPane();
33        container.setLayout( new FlowLayout() );
34
35        // create label and text field for die 1
36        die1Label = new JLabel( "Die 1" );
37        container.add( die1Label );
38        die1Field = new JTextField( 10 );
39        die1Field.setEditable( false );
40        container.add( die1Field );
41
42        // create label and text field for die 2
43        die2Label = new JLabel( "Die 2" );
44        container.add( die2Label );
45        die2Field = new JTextField( 10 );
46        die2Field.setEditable( false );
47        container.add( die2Field );
48
49        // create label and text field for sum
50        sumLabel = new JLabel( "Sum is" );
51        container.add( sumLabel );
52        sumField = new JTextField( 10 );
53        sumField.setEditable( false );
54        container.add( sumField );
55
56        // create label and text field for point
57        pointLabel = new JLabel( "Point is" );
58        container.add( pointLabel );
59        pointField = new JTextField( 10 );
60        pointField.setEditable( false );
61        container.add( pointField );
62
63        // create button user clicks to roll dice
64        rollButton = new JButton( "Roll Dice" );
65        rollButton.addActionListener( this );
66        container.add( rollButton );
67     }
68
69     // process one roll of dice
70     public void actionPerformed( ActionEvent actionEvent )
71     {
72        // first roll of dice
73        if ( firstRoll ) {
74           sumOfDice = rollDice();      // roll dice
```

Fig. 6.9 Program to simulate the game of craps (part 2 of 5).

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```
75
76          switch ( sumOfDice ) {
77
78             // win on first roll
79             case 7: case 11:
80                gameStatus = WON;
81                pointField.setText( "" );   // clear point field
82                break;
83
84             // lose on first roll
85             case 2: case 3: case 12:
86                gameStatus = LOST;
87                pointField.setText( "" );   // clear point field
88                break;
89
90             // remember point
91             default:
92                gameStatus = CONTINUE;
93                myPoint = sumOfDice;
94                pointField.setText( Integer.toString( myPoint ) );
95                firstRoll = false;
96                break;
97
98          }  // end switch structure
99
100      }  // end if structure body
101
102      // subsequent roll of dice
103      else {
104         sumOfDice = rollDice();      // roll dice
105
106         // determine game status
107         if ( sumOfDice == myPoint )  // win by making point
108            gameStatus = WON;
109         else
110            if ( sumOfDice == 7 )     // lose by rolling 7
111               gameStatus = LOST;
112      }
113
114      // display message indicating game status
115      displayMessage();
116
117   }  // end method actionPerformed
118
119   // roll dice, calculate sum and display results
120   public int rollDice()
121   {
122      int die1, die2, sum;
123
124      // pick random die values
125      die1 = 1 + ( int ) ( Math.random() * 6 );
126      die2 = 1 + ( int ) ( Math.random() * 6 );
127
```

Fig. 6.9 Program to simulate the game of craps (part 3 of 5).

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```
128         sum = die1 + die2;   // sum die values
129
130         // display results
131         die1Field.setText( Integer.toString( die1 ) );
132         die2Field.setText( Integer.toString( die2 ) );
133         sumField.setText( Integer.toString( sum ) );
134
135         return sum;  // return sum of dice
136
137      }  // end method rollDice
138
139      // determine game status and display appropriate message
140      // in status bar
141      public void displayMessage()
142      {
143         // game should continue
144         if ( gameStatus == CONTINUE )
145            showStatus( "Roll again." );
146
147         // game won or lost
148         else {
149
150            if ( gameStatus == WON )
151               showStatus( "Player wins. " +
152                  "Click Roll Dice to play again." );
153            else
154               showStatus( "Player loses. " +
155                  "Click Roll Dice to play again." );
156
157            // next roll is first roll of new game
158            firstRoll = true;
159         }
160
161      }  // end method displayMessage
162
163   }  // end class Craps
```

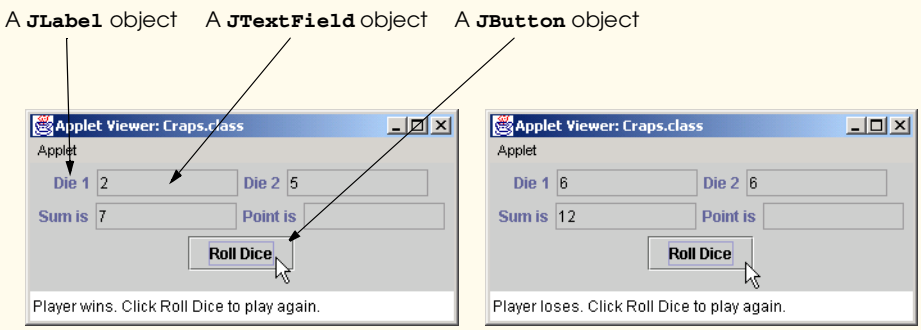

Fig. 6.9 Program to simulate the game of craps (part 4 of 5).

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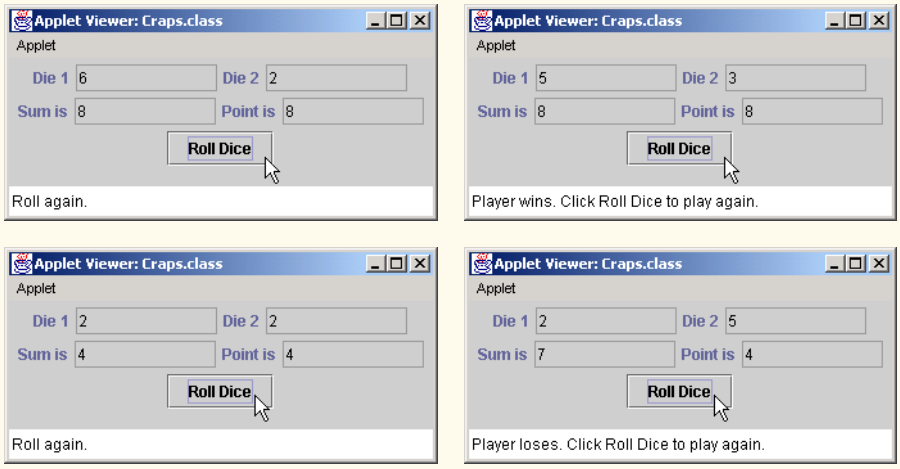

Fig. 6.9 Program to simulate the game of craps (part 5 of 5).

Notice that the player must roll two dice on the first and all subsequent rolls. When you execute the applet, click the **Roll Dice** button to play the game. The lower left corner of the **appletviewer** window displays the result of each roll. The screen captures show four separate executions of the applet (a win and a loss on the first roll, and a win and a loss after the first roll).

Until now, most user interactions in our programs have been through either an input dialog (in which the user could type an input value for the program) or a message dialog (in which a message was displayed to the user, and the user could click **OK** to dismiss the dialog). Although these dialogs are valid ways to receive input from a user and display output in a Java program, their capabilities are fairly limited—an input dialog can obtain only one value at a time from the user and a message dialog can display only one message. It is much more common to receive multiple inputs from the user at once (such as the user entering name and address information) or display many pieces of data at once (such as the values of the dice, the sum of the dice and the point, in this example). To begin our introduction to more elaborate user interfaces, this program illustrates two new graphical user interface concepts: Attaching several GUI components to an applet and GUI *event handling*. We discuss each of the new issues as they are encountered in the program.

The **import** statements in lines 5–9 enable the compiler to load the classes used in this applet. Line 5 specifies that the program uses classes from package **java.awt** (specifically, classes **Container** and ***FlowLayout***). Line 6 specifies that the program uses classes from package ***java.awt.event***. This package contains many data types that enable a program to process a user's interactions with a program's GUI. In this program, we use the ***ActionListener*** and ***ActionEvent*** data types from package **java.awt.event**. Line 9 specifies that the program uses classes from package **javax.swing** (specifically, **JApplet**, ***JLabel***, ***JTextField*** and ***JButton***).

As stated earlier, every Java program is based on at least one class definition that extends and enhances an existing class definition via inheritance. Remember that applets inherit from class **JApplet**. Line 11 indicates that class **Craps** inherits from **JApplet**

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and *implements* ***ActionListener***. A class can inherit existing attributes and behaviors (data and methods) from another class specified to the right of keyword **extends** in the class definition. In addition, a class can implement one or more *interfaces*. An interface specifies one or more behaviors (i.e., methods), which you must define in your class definition. Implementing interface **ActionListener** forces us to *define a method* with the first line

```
public void actionPerformed( ActionEvent actionEvent )
```

in our **Craps** class. This method's task is to process a user's interaction with the **JButton** (called **Roll Dice** on the user interface). When the user presses the button, this method will be called automatically in response to the user interaction. This process is called *event handling*. The *event* is the user interaction (i.e., pressing the button). The *event handler* is method **actionPerformed**. We discuss the details of this interaction and method **actionPerformed** shortly. Chapter 9, Object-Oriented Programming, discusses interfaces in detail. For now, as you develop your own applets that have graphical user interfaces, mimic the features that support event handling of the GUI components we present.

The game of craps is reasonably involved. The player may win or lose on the first roll, or may win or lose on any roll. Line 14 creates variables that define the three states of a game of craps: Game won (**WON**), game lost (**LOST**) or continue rolling the dice (**CONTINUE**). Keyword ***final*** at the beginning of the declaration indicates that these are *constant variables*. When a program declares a **final** variable, the program must initialize the variable before using the variable and cannot modify the variable thereafter. If the variable is an instance variable, this initialization normally occurs in the variable's declaration. The initialization also can occur in a special method of a class called a *constructor* (discussed in Chapter 8). Constant variables are often called *named constants* or *read-only variables*. We provide more details on keyword **final** in Chapter 7 and Chapter 8.

Common Programming Error 6.12

After declaring and initializing a ***final*** *variable, attempting to assign another value to that variable is a syntax error.*

Good Programming Practice 6.5

Use only uppercase letters (with underscores between words) in the names of ***final*** *variables. This format makes these constants stand out in a program.*

Good Programming Practice 6.6

Using meaningfully named ***final*** *variables rather than integer constants (such as 2) makes programs more readable.*

Lines 17–20 declare several instance variables that are used throughout the **Craps** applet. Variable **firstRoll** is a **boolean** variable that indicates whether the next roll of the dice is the first roll in the current game. Variable **sumOfDice** maintains the sum of the dice for the last roll. Variable **myPoint** stores the "point" if the player does not win or lose on the first roll. Variable **gameStatus** keeps track of the current state of the game (**WON**, **LOST** or **CONTINUE**).

Lines 23–25 declare references to the GUI components used in this applet's graphical user interface. References **die1Label**, **die2Label**, **sumLabel** and **pointLabel** all refer to ***JLabel*** *objects*. A **JLabel** contains a string of characters to be displayed on the

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screen. Normally, a **JLabel** indicates the purpose of another GUI component on the screen. In the screen captures of Fig. 6.9, the **JLabel** objects are the text to the left of each rectangle in the first two rows of the user interface. References **die1Field**, **die2Field**, **sumField** and **pointField** all refer to ***JTextField*** *objects*. **JTextField**s are used to get a single line of information from the user at the keyboard or to display information on the screen. The **JTextField** objects are the rectangles to the right of each **JLabel** in the first two rows of the user interface. *Reference* **rollButton** refers to a ***JButton*** *object*. When the user presses a **JButton**, the program normally responds by performing a task (rolling the dice, in this example). The **JButton** object is the rectangle containing the words **Roll Dice** at the bottom of the user interface shown in Fig. 6.9. We have seen **JButton**s in prior programs—every message dialog and every input dialog contained an **OK** button to dismiss the message dialog or send the user's input to the program. We also have seen **JTextField**s in prior programs—every input dialog contains a **JTextField** in which the user types an input value.

Method **init** (lines 28–67) creates the GUI component objects and attaches them to the user interface. Line 32 declares **Container** reference **container** and assigns to it the result method **getContentPane**. Remember, method **getContentPane** returns a reference to the applet's content pane that can be used to attach GUI components to the applet's user interface.

Line 33 uses **Container** method ***setLayout*** to specify the *layout manager* for the applet's user interface. Layout managers arrange GUI components on a **Container** for presentation purposes. The layout managers determine the position and size of every GUI component attached to the container, thereby processing most of the layout details and enabling the programmer to concentrate on the basic look and feel of the programs.

FlowLayout is the simplest layout manager. GUI components are placed from left to right in the order in which they are attached to the **Container** (the applet's content pane in this example) with method **add**. When the layout manager reaches the edge of the container, it begins a new row of components and continues laying out the components on that row. Line 33 creates a new object of class **FlowLayout** and passes it as the argument to method **setLayout**. Normally, the layout is set before any GUI components are added to a **Container**.

Common Programming Error 6.13

*If a **Container** is not large enough to display the GUI component attached to it, some or all of the GUI components simply will not display.*

[*Note*: Each **Container** can have only one layout manager at a time. Separate **Container**s in the same program can have different layout managers. Most Java programming environments provide GUI design tools that help a programmer graphically design a GUI; then the tools write Java code to create the GUI. Some of these GUI design tools also allow the programmer to use layout managers. Chapter 12 and Chapter 13 discuss several layout managers that allow more precise control over the layout of the GUI components.]

Lines 36–40, 43–47, 50–54 and 57–61 each create a **JLabel** and **JTextField** pair and attach them to the user interface. Since these sets of lines are all quite similar, we concentrate on lines 36–40. Line 36 creates a new **JLabel** object, initializes it with the string **"Die 1"** and assigns the object to reference **die1Label**. This procedure labels the corresponding **JTextField** (named **die1Field**) in the user interface, so the user can deter-

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mine the purpose of the value displayed in **die1Field**. Line 37 attaches the **JLabel** to which **die1Label** refers to the applet's content pane. Line 38 creates a new **JTextField** object, initializes it to be **10** characters wide and assigns the object to reference **die1Field**. This **JTextField** displays the value of the first die after each roll of the dice. Line 39 uses **JTextField** method **setEditable** with the argument **false** to indicate that the user should not be able to type in the **JTextField**. This setting makes the **JTextField** *uneditable* and causes it to be displayed with a gray background by default. An editable **JTextField** has a white background (as seen in input dialogs). Line 32 attaches the **JTextField** to which **die1Field** refers to the applet's content pane.

Line 64 creates a new **JButton** object, initializes it with the string **"Roll Dice"** (this string will appear on the button) and assigns the object to reference **rollButton**.

Line 65 specifies that ***this*** applet should *listen* for events from the **rollButton**. The **this** keyword enables the applet to refer to itself. (We discuss **this** in detail in Chapter 8.) When the user interacts with a GUI component an *event* is sent to the applet. GUI events are messages (method calls) indicating that the user of the program has interacted with one of the program's GUI components. For example, when you press **rollButton** in this program, a message indicating the event that occurred is sent to the applet to notify the applet that you pressed the button. For a **JButton**, the message indicates to the applet that *an action was performed* by the user on the **JButton** and automatically calls method **actionPerformed** to process the user's interaction.

This style of programming is known as *event-driven programming*—the user interacts with a GUI component, the program is notified of the event and the program processes the event. The user's interaction with the GUI "drives" the program. The methods that are called when an event occurs are also known as *event-handling methods*. When a GUI event occurs in a program, Java creates an object containing information about the event that occurred and *calls* an appropriate event-handling method. Before any event can be processed, each GUI component must know which object in the program defines the event-handling method that will be called when an event occurs. In line 65, **JButton** method ***addActionListener*** is used to tell **rollButton** that the applet (**this**) can *listen* for *action events* and defines method **actionPerformed**. This procedure is called *registering the event handler* with the GUI component. (We also like to call it the *start-listening line*, because the applet is now listening for events from the button.) To respond to an action event, we must define a class that implements **ActionListener** (this requires that the class also define method **actionPerformed**), and we must register the event handler with the GUI component. Finally, the last line in **init** attaches the **JButton** to which **roll** refers to the applet's content pane, thus completing the user interface.

Method **actionPerformed** (lines 70–117) is one of several methods that process interactions between the user and GUI components. The first line of the method indicates that **actionPerformed** is a **public** method that returns nothing (**void**) when it completes its task. Method **actionPerformed** receives one argument—an **ActionEvent**—when it is called in response to an action performed on a GUI component by the user (in this case, pressing the **JButton**). The **ActionEvent** argument contains information about the action that occurred.

We define method **rollDice** (lines 120–137) to roll the dice and compute and display their sum. Method **rollDice** is defined once, but it is called from two places in the program (lines 74 and 104). Method **rollDice** takes no arguments, so it has an empty

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parameter list. Method **rollDice** returns the sum of the two dice, so a return type of **int** is indicated in the method's header.

The user clicks **Roll Dice** to roll the dice. This action invokes method **actionPerformed** (line 70) of the applet. Method **actionPerformed** checks the **boolean** variable **firstRoll** (line 73) to determine if it is **true** or **false**. If it is **true**, this roll is the first roll of the game. Line 74 calls **rollDice**, which picks two random values from 1 to 6, displays the value of the first die, second die and the sum of the dice in the first three **JTextField**s, respectively, and returns the sum of the dice. Note that the integer values are converted to **String**s (lines 131–133) with **static** method **Integer.toString**, because **JTextField**s can display only **String**s. After the first roll, the nested **switch** structure at line 76 in **actionPerformed** determines if the game has been won or lost, or if the game should continue with another roll. After the first roll, if the game is not over, **sumOfDice** is saved in **myPoint** and displayed in **pointField**.

Line 115 calls method **displayMessage** (defined at lines 141–161) to display the current status of the game. The **if/else** structure at line 144 uses applet method ***showStatus*** to display a **String** in the applet container's status bar. Line 145 displays

```
Roll again.
```

if **gameStatus** is equal to **CONTINUE**. Lines 150–151 display

```
Player wins. Click Roll Dice to play again.
```

if **gameStatus** is equal to **WON**. Lines 153–154 display

```
Player loses. Click Roll Dice to play again.
```

if **gameStatus** is equal to **LOST**. Method **showStatus** receives a **String** argument and displays it in the status bar of the applet container. If the game is over (i.e., it has been won or lost) line 158 sets **firstRoll** to **true** to indicate that the next roll of the dice is the first roll of the next game.

The program then waits for the user to click the **Roll Dice** button again. Each time the user presses **Roll Dice** button, method **actionPerformed** invokes method **rollDice** to produce a new **sumOfDice**. If the current roll is a continuation of an incomplete game, the code in lines 103–112 executes. In line 107, if **sumOfDice** matches **myPoint**, line 108 sets **gameStatus** to **WON**, and the game is complete. In line 110, if **sumOfDice** is equal to **7**, line 111 sets **gameStatus** to **LOST**, and the game is complete. When the game completes, **displayMessage** displays an appropriate message, and the user can click the **Roll Dice** button to begin a new game. Throughout the program, the four **JTextField**s are updated with the new values of the dice and the sum on each roll, and the **pointField** is updated each time a new game begins.

Note the interesting use of the various program control mechanisms we have discussed. The craps program uses four methods—**init**, **actionPerformed**, **rollDice** and **displayMessage**—and the **switch**, **if/else** and nested **if** structures. Note also the use of multiple **case** labels in the **switch** structure to execute the same statements (lines 79 and 85). Also, note that the event-handling mechanism acts as a form of program control. In this program, event-handling enables user-controlled repetition—each time the user clicks **Roll Dice**, the program rolls the dice again. In the exercises, we investigate various interesting characteristics of the game of craps.

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6.10 Duration of Identifiers

Chapter 2 through Chapter 5 used identifiers for variable names and reference names. The attributes of variables and references include name, type, size and value. We also use identifiers as names for user-defined methods and classes. Actually, each identifier in a program has other attributes, including *duration* and *scope*.

An identifier's *duration* (also called its *lifetime*) is the period during which the identifier exists in memory. Some identifiers exist for brief periods of time and others exist for the entire execution of a program.

An identifier's *scope* defines where the identifier can be referenced in a program. Some identifiers can be referenced throughout a program, while others can be referenced only from limited portions of a program. This section discusses duration of identifiers. Section 6.11 discusses the scope of identifiers.

Identifiers that represent local variables in a method (i.e., parameters and variables declared in the body of the method) have *automatic duration*. Automatic-duration variables are created when program control reaches their declaration; they exist while the block in which they are declared is active; and they are destroyed when the block in which they are declared is exited. We will continue to refer to variables of automatic duration as *local variables*.

Performance Tip 6.2

Automatic duration is a means of conserving memory, because automatic-duration variables are created when program control reaches their declaration and are destroyed when the block in which they are declared is exited.

The instance variables of a class are initialized automatically by the compiler if the programmer does not provide explicit initial values. Variables of the primitive data types are initialized to zero, except **`boolean`** variables, which are initialized to **`false`**. References are initialized to **`null`**. Unlike instance variables of a class, automatic variables must be initialized by the programmer before they can be used.

Testing and Debugging Tip 6.2

If an automatic variable is not initialized before it is used in a method, the compiler issues an error message.

Java also has identifiers of *static duration*. Variables and references of static duration exist from the point at which the class that defines them is loaded into memory for execution until the program terminates. Their storage is allocated and initialized when their classes are loaded into memory. Even though static-duration variables and reference names exist when their classes are loaded into memory, these identifiers cannot necessarily be used throughout a program. Duration (an identifier's lifetime) and scope (where an identifier can be used) are separate issues, as shown in Section 6.11.

Software Engineering Observation 6.9

Automatic duration is an example of the principle of least privilege*. This principle states that each component of a system should have sufficient rights and privileges to accomplish its designated task, but no additional rights or privileges. This constraint helps prevent accidental and/or malicious errors from occurring in systems. Why have variables stored in memory and accessible when they are not needed?*

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6.11 Scope Rules

The *scope* of an identifier for a variable, reference or method is the portion of the program that can reference the identifier. A local variable or reference declared in a block can be used only in that block or in blocks nested within that block. The scopes for an identifier are *class scope* and *block scope*. There is also a special scope for labels used with the **`break`** and **`continue`** statements (introduced in Chapter 5, "Control Structures: Part 2"). A label is visible only in the body of the repetition structure that immediately follows the label.

Methods and instance variables of a class have *class scope*. Class scope begins at the opening left brace, **`{`**, of the class definition and terminates at the closing right brace, **`}`**, of the class definition. Class scope enables methods of a class to invoke directly all methods defined in that same class or inherited into that class (such as the methods inherited into our applets from class **`JApplet`**) and to access directly all instance variables defined in the class. In Chapter 8, we will see that **`static`** methods are an exception to this rule. In a sense, all instance variables and methods of a class are *global* to the methods of the class in which they are defined (i.e., the methods can modify the instance variables directly and invoke other methods of the class). [*Note*: One of the reasons we use mainly applets in this chapter is to simplify our discussions. We have not as yet introduced a true windowed application in which the methods of our application class will have access to all the other methods of the class and the instance variables of the class.]

Identifiers declared inside a block have *block scope*. Block scope begins at the identifier's declaration and ends at the terminating right brace (**`}`**) of the block. Local variables of a method have block scope, as do method parameters, which are also local variables of the method. Any block may contain variable or reference declarations. When blocks are nested in a method's body and an identifier declared in an outer block has the same name as an identifier declared in an inner block, the compiler generates a syntax error stating that the variable is already defined. If a local variable in a method has the same name as an instance variable, the instance variable is "hidden" until the block terminates execution. In Chapter 8, we discuss how to access such "hidden" instance variables.

Common Programming Error 6.14

Accidentally using the same name for an identifier in an inner block of a method as is used for an identifier in an outer block of the same method results in a syntax error from the compiler.

Good Programming Practice 6.7

Avoid local-variable names that hide instance-variable names. This can be accomplished by avoiding the use of duplicate identifiers in a class.

The applet of Fig. 6.10 demonstrates scoping issues with instance variables and local variables.

This example uses the applet's **`start`** method (lines 27–40) for the first time. Remember, when an applet container loads an applet, the container first creates an instance of the applet class. It then calls the applet's **`init`**, **`start`** and **`paint`** methods. Method **`start`** always is defined with the line shown on line 27 as its first line.

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```
1  // Fig. 6.10: Scoping.java
2  // A scoping example.
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class Scoping extends JApplet {
11    JTextArea outputArea;
12
13    // instance variable accessible to all methods of this class
14    int x = 1;
15
16    // set up applet's GUI
17    public void init()
18    {
19       outputArea = new JTextArea();
20       Container container = getContentPane();
21       container.add( outputArea );
22
23    }  // end method init
24
25    // method start called after init completes; start calls
26    // methods useLocal and useInstance
27    public void start()
28    {
29       int x = 5;    // variable local to method start
30
31       outputArea.append( "local x in start is " + x );
32
33       useLocal();       // useLocal has local x
34       useInstance();    // useInstance uses instance variable x
35       useLocal();       // useLocal reinitializes local x
36       useInstance();    // instance variable x retains its value
37
38       outputArea.append( "\n\nlocal x in start is " + x );
39
40    }  // end method start
41
42    // useLocal reinitializes local variable x during each call
43    public void useLocal()
44    {
45       int x = 25;  // initialized each time useLocal is called
46
47       outputArea.append( "\n\nlocal x in useLocal is " + x +
48          " after entering useLocal" );
49       ++x;
50       outputArea.append( "\nlocal x in useLocal is " + x +
51          " before exiting useLocal" );
52
53    }  // end method useLocal
```

Fig. 6.10 A scoping example (part 1 of 2).

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```
54
55     // useInstance modifies instance variable x during each call
56     public void useInstance()
57     {
58        outputArea.append( "\n\ninstance variable x is " + x +
59                           " on entering useInstance" );
60        x *= 10;
61        outputArea.append( "\ninstance variable x is " + x +
62                           " on exiting useInstance" );
63
64     }  // end method useInstance
65
66  }  // end class Scoping
```

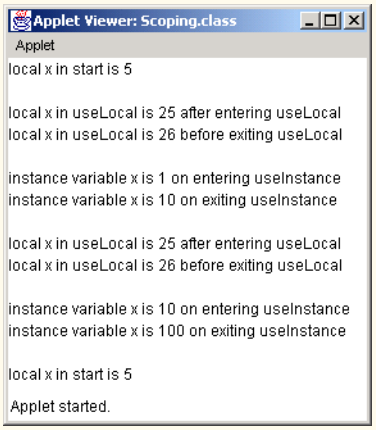

Fig. 6.10 A scoping example (part 2 of 2).

Line 14 declares and initializes instance variable **x** to **1**. This instance variable is hidden in any block (or method) that declares a variable named **x**. Method **start** declares a local variable **x** (line 29) and initializes it to **5**. This variable's value is displayed in the **JTextArea outputArea** to show that the instance variable **x** is hidden in **start**. The program defines two other methods—**useLocal** (lines 43–53) and **useInstance** (lines 56–64)—that each take no arguments and do not return results. Method **start** calls each of these methods twice. Method **useLocal** defines local (automatic) variable **x** (line 45). When **useLocal** is called (line 33), it creates local variable **x** and initializes **x** to **25**, displays the value of **x** in **outputArea**, increments **x** and displays the value of **x** again. When **uselLocal** is called again (line 35), it recreates local variable **x** and initializes **x** to **25**. Method **useInstance** does not declare any variables. Therefore, when it refers to variable **x**, the instance variable **x** is used. When **useInstance** is called (line 34), it displays the instance variable **x** in **outputArea**, multiplies the instance variable **x** by **10** and displays instance variable **x** again before returning. The next time method **useInstance** is called (line 36), the instance variable has its modified value, **10**. Finally, the program displays the local variable **x** in **start** again to show that none of the method calls modified the value of **x**, because the methods all referred to variables in other scopes.

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6.12 Recursion

The programs we have discussed thus far are generally structured as methods that call one another in a disciplined, hierarchical manner. For some problems, however, it is useful to have methods call themselves. A *recursive method* is a method that calls itself either directly or indirectly through another method. Recursion is an important topic discussed at length in upper-level computer science courses. In this and the next section, simple examples of recursion are presented. This book contains an extensive treatment of recursion. Figure 6.15 (at the end of Section 6.14) summarizes the recursion examples and exercises in this book.

We consider recursion conceptually first. Then we examine several programs containing recursive methods. Recursive problem-solving approaches have a number of elements in common. A recursive method is called to solve a problem. The method actually knows how to solve only the simplest case(s) or so-called *base case(s)*. If the method is called with a base case, the method returns a result. If the method is called with a more complex problem, the method divides the problem into two conceptual pieces: a piece that the method knows how to do (base case) and a piece that the method does not know how to do. To make recursion feasible, the latter piece must resemble the original problem, but be a slightly simpler or slightly smaller version of the original problem. Because this new problem looks like the original problem, the method invokes (calls) a fresh copy of itself to go to work on the smaller problem; this procedure is referred to as a *recursive call* and is also called the *recursion step*. The recursion step also normally includes the keyword **`return`**, because its result will be combined with the portion of the problem the method knew how to solve to form a result that will be passed back to the original caller.

The recursion step executes while the original call to the method is still open (i.e., while it has not finished executing). The recursion step can result in many more recursive calls, as the method divides each new subproblem into two conceptual pieces. For the recursion eventually to terminate, each time the method calls itself with a slightly simpler version of the original problem, the sequence of smaller and smaller problems must converge on the base case. At that point, the method recognizes the base case, and returns a result to the previous copy of the method, and a sequence of returns ensues up the line until the original method call eventually returns the final result to the caller. This process sounds exotic when compared with the conventional problem solving we have performed to this point. As an example of these concepts at work, let us write a recursive program to perform a popular mathematical calculation.

The factorial of a nonnegative integer n, written $n!$ (and pronounced "n factorial"), is the product

$$n \cdot (n - 1) \cdot (n - 2) \cdot \ldots \cdot 1$$

where 1! is equal to 1 and 0! is defined to be 1. For example, 5! is the product $5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$, which is equal to 120.

The factorial of an integer, **`number`**, greater than or equal to 0, can be calculated *iteratively* (nonrecursively) using the **`for`** structure as follows:

```
factorial = 1;

for ( int counter = number; counter >= 1; counter-- )
   factorial *= counter;
```

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A recursive definition of the factorial method is arrived at by observing the following relationship:

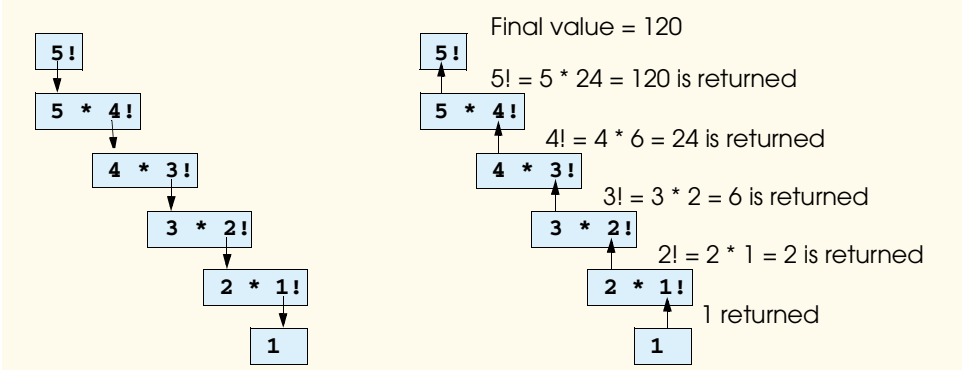
$$n! = n \cdot (n - 1)!$$

For example, 5! is clearly equal to 5 * 4!, as is shown by the following equations:

$$5! = 5 \cdot 4 \cdot 3 \cdot 2 \cdot 1$$
$$5! = 5 \cdot (4 \cdot 3 \cdot 2 \cdot 1)$$
$$5! = 5 \cdot (4!)$$

The evaluation of 5! would proceed as shown in Fig. 6.11. Figure 6.11 (a) shows how the succession of recursive calls proceeds until 1! is evaluated to be 1, which terminates the recursion. Figure 6.11 (b) shows the values returned from each recursive call to its caller until the final value is calculated and returned.

Figure 6.12 uses recursion to calculate and print the factorials of the integers from 0 to 10. (The choice of the data type **`long`** will be explained momentarily.) The recursive method **`factorial`** (lines 29–39) first tests to determine whether a terminating condition (line 32) is **`true`**. If **`number`** is less than or equal to **`1`** (the base case), **`factorial`** returns **`1`**, no further recursion is necessary and the method returns. If **`number`** is greater than **`1`**, line 37 expresses the problem as the product of **`number`** and a recursive call to **`factorial`** evaluating the factorial of **`number - 1`**. Note that **`factorial( number - 1 )`** is a slightly simpler problem than the original calculation **`factorial( number )`**.



(a) Procession of recursive calls. (b) Values returned from each recursive call.

Fig. 6.11 Recursive evaluation of 5!.

```
1  // Fig. 6.12: FactorialTest.java
2  // Recursive factorial method
3
4  // Java core packages
5  import java.awt.*;
6
```

Fig. 6.12 Calculating factorials with a recursive method (part 1 of 2).

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```
// Java extension packages
import javax.swing.*;

public class FactorialTest extends JApplet {
   JTextArea outputArea;

   // initialize applet by creating GUI and calculating factorials
   public void init()
   {
      outputArea = new JTextArea();

      Container container = getContentPane();
      container.add( outputArea );

      // calculate the factorials of 0 through 10
      for ( long counter = 0; counter <= 10; counter++ )
         outputArea.append( counter + "! = " +
            factorial( counter ) + "\n" );

   }  // end method init

   // Recursive definition of method factorial
   public long factorial( long number )
   {
      // base case
      if ( number <= 1 )
         return 1;

      // recursive step
      else
         return number * factorial( number - 1 );

   }  // end method factorial

}  // end class FactorialTest
```

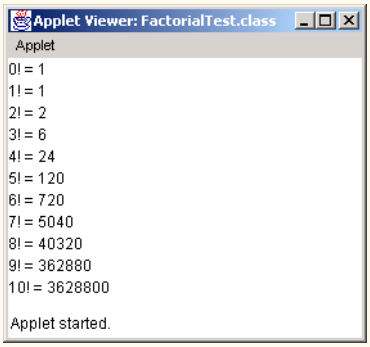

Fig. 6.12 Calculating factorials with a recursive method (part 2 of 2).

Method **factorial** (line 29) receives a parameter of type **long** and returns a result of type **long**. As can be seen in Fig. 6.12, factorial values become large quickly. We chose data type **long** so the program can calculate factorials greater than 20!. Unfortunately, the

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factorial method produces large values so quickly that even **long** does not help us print many factorial values before the values exceed the size that can be stored in a **long** variable.

We explore in the exercises the fact that **float** and **double** may ultimately be needed by users desiring to calculate factorials of larger numbers. This situation points to a weakness in most programming languages, namely, that the languages are not easily extended to handle the unique requirements of various applications. As we will see in Chapter 9, Object-Oriented Programming, Java is an extensible language that allows us to create arbitrarily large integers if we wish. In fact, package **java.math** provides two classes—**BigInteger** and **BigDecimal**—explicitly for mathematical calculations of arbitrary precision that cannot be represented with Java's primitive data types.

Common Programming Error 6.15

Either omitting the base case or writing the recursion step incorrectly so that it does not converge on the base case will cause infinite recursion, eventually exhausting memory. This error is analogous to the problem of an infinite loop in an iterative (nonrecursive) solution.

6.13 Example Using Recursion: The Fibonacci Series

The Fibonacci series,

0, 1, 1, 2, 3, 5, 8, 13, 21, …

begins with 0 and 1 and has the property that each subsequent Fibonacci number is the sum of the previous two Fibonacci numbers.

The series occurs in nature and, in particular, describes a form of spiral. The ratio of successive Fibonacci numbers converges on a constant value of 1.618…. This number, too, repeatedly occurs in nature and has been called the *golden ratio*, or the *golden mean.* Humans tend to find the golden mean aesthetically pleasing. Architects often design windows, rooms and buildings whose length and width are in the ratio of the golden mean. Postcards are often designed with a golden-mean length/width ratio.

The Fibonacci series may be defined recursively as follows:

fibonacci(0) = 0
fibonacci(1) = 1
fibonacci(n) = fibonacci(n – 1) + fibonacci(n – 2)

Note that there are two base cases for the Fibonacci calculation: fibonacci(0) is defined to be 0, and fibonacci(1) is defined to be 1. The applet of Fig. 6.13 calculates the i^{th} Fibonacci number recursively, using method **fibonacci** (lines 68–78). The applet enables the user to input an integer in a **JTextField**. The value input indicates the i^{th} Fibonacci number to calculate. When the user presses the *Enter* key, method **actionPerformed** executes in response to the user interface event and calls method **fibonacci** to calculate the specified Fibonacci number. Fibonacci numbers tend to become large quickly. Therefore, we use data type **long** as the parameter type and the return type of **fibonacci**. In Fig. 6.13, the screen captures show the results of calculating several Fibonacci numbers.

Once again, method **init** of this applet creates the GUI components and attaches them to the applet's content pane. The layout manager for the content pane is set to **FlowLayout** at line 22.

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The event handling in this example is similar to the event handling of the **Craps** applet in Fig. 6.9. Line 34 specifies that **this** applet should listen for events from the **JTextField numberField**. Remember, the **this** keyword enables the applet to refer to itself. So, in line 34, the applet is telling **numberField** that the applet should be notified (with a call to the applet's **actionPerformed** method) when an action event occurs in the **numberField**. In this example, the user presses the *Enter* key while typing in the **numberField** to generate the action event. A message is then sent to the applet (i.e., a method—**actionPerformed**—is called on the applet) indicating that the user of the program has interacted with one of the program's GUI components (**numberField**). Remember that the statement to register the applet as the **numberField**'s listener will compile only if the applet class also implements **ActionListener** (line 12).

```
1  // Fig. 6.13: FibonacciTest.java
2  // Recursive fibonacci method
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class FibonacciTest extends JApplet
12    implements ActionListener {
13
14    JLabel numberLabel, resultLabel;
15    JTextField numberField, resultField;
16
17    // set up applet's GUI
18    public void init()
19    {
20       // obtain content pane and set its layout to FlowLayout
21       Container container = getContentPane();
22       container.setLayout( new FlowLayout() );
23
24       // create numberLabel and attach it to content pane
25       numberLabel =
26          new JLabel( "Enter an integer and press Enter" );
27       container.add( numberLabel );
28
29       // create numberField and attach it to content pane
30       numberField = new JTextField( 10 );
31       container.add( numberField );
32
33       // register this applet as numberField's ActionListener
34       numberField.addActionListener( this );
35
36       // create resultLabel and attach it to content pane
37       resultLabel = new JLabel( "Fibonacci value is" );
38       container.add( resultLabel );
39
```

Fig. 6.13 Recursively generating Fibonacci numbers (part 1 of 3).

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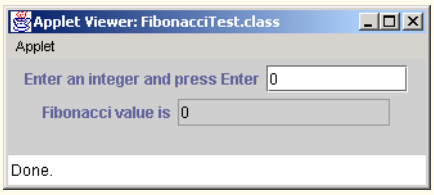
```
40          // create numberField, make it uneditable
41          // and attach it to content pane
42          resultField = new JTextField( 15 );
43          resultField.setEditable( false );
44          container.add( resultField );
45
46       }  // end method init
47
48       // obtain user input and call method fibonacci
49       public void actionPerformed( ActionEvent e )
50       {
51          long number, fibonacciValue;
52
53          // obtain user's input and conver to long
54          number = Long.parseLong( numberField.getText() );
55
56          showStatus( "Calculating ..." );
57
58          // calculate fibonacci value for number user input
59          fibonacciValue = fibonacci( number );
60
61          // indicate processing complete and display result
62          showStatus( "Done." );
63          resultField.setText( Long.toString( fibonacciValue ) );
64
65       }  // end method actionPerformed
66
67       // Recursive definition of method fibonacci
68       public long fibonacci( long n )
69       {
70          // base case
71          if ( n == 0 || n == 1 )
72             return n;
73
74          // recursive step
75          else
76             return fibonacci( n - 1 ) + fibonacci( n - 2 );
77
78       }  // end method fibonacci
79
80    }  // end class FibonacciTest
```



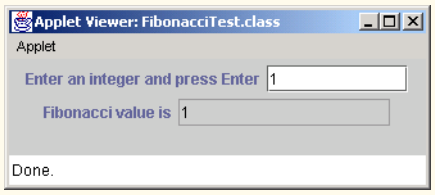


Fig. 6.13 Recursively generating Fibonacci numbers (part 2 of 3).

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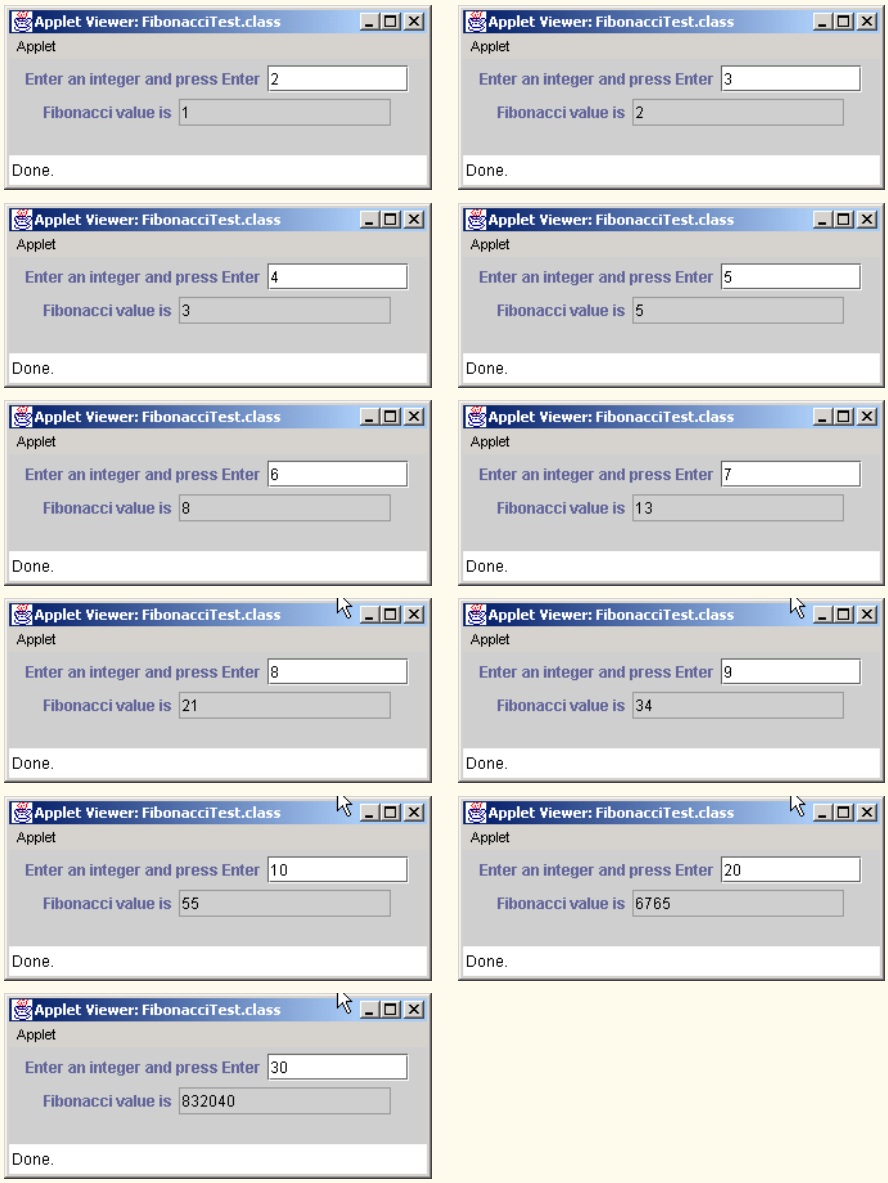

Fig. 6.13 Recursively generating Fibonacci numbers (part 3 of 3).

The call to **`fibonacci`** (line 59) from **`actionPerformed`** is not a recursive call, but all subsequent calls to **`fibonacci`** performed from the body of **`fibonacci`** are recursive. Each time **`fibonacci`** is invoked, it immediately tests for the base case—**`n`** equal to 0 or 1. If this condition is true, **`fibonacci`** returns **`n`** (fibonacci(0) is 0, and fibonacci(1) is 1). Interestingly, if **`n`** is greater than 1, the recursion step generates *two* recursive calls, each for a slightly simpler problem than the original call to **`fibonacci`**.

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Figure 6.14 shows how method **fibonacci** evaluates **fibonacci(3)**. In the figure, **f** is an abbreviation for **fibonacci**.

Figure 6.14 raises some interesting issues about the order in which Java compilers evaluate the operands of operators. This issue is different than the order in which operators are applied to their operands, namely the order dictated by the rules of operator precedence. From Fig. 6.14, it appears that while **f(3)** is being evaluated, two recursive calls will be made, namely **f(2)** and **f(1)**. But in what order will these calls be made? Most programmers assume that the operands will be evaluated left to right. In Java, this assumption is true.

The C and C++ languages (on which many of Java's features are based) do not specify the order in which the operands of most operators (including **+**) are evaluated. Therefore, the programmer can make no assumption in those languages about the order in which the calls in this example execute. The calls could, in fact, execute **f(2)** first and **f(1)** second, or the calls could be executed in the reverse order: **f(1)**, then **f(2)**. In this program and in most other programs, it turns out that the final result would be the same for either case. But in some programs, the evaluation of an operand may have *side effects* that could affect the final result of the expression.

The Java language specifies that the order of evaluation of the operands is from left to right. Thus, the method calls are in fact **f(2)** first and **f(1)** second.

Good Programming Practice 6.8

Do not write expressions that depend on the order of evaluation of the operands of an operator. Use of such expressions often results in programs that are difficult to read, debug, modify and maintain.

A word of caution is in order about recursive programs like the one we use here to generate Fibonacci numbers. Each invocation of the **fibonacci** method that does not match one of the base cases (i.e., 0 or 1) results in two more recursive calls to the **fibonacci** method. This set of recursive calls rapidly gets out of hand. Calculating the Fibonacci value of 20 using the program in Fig. 6.13 requires 21,891 calls to the **fibonacci** method; calculating the Fibonacci value of 30 requires 2,692,537 calls to the **fibonacci** method.

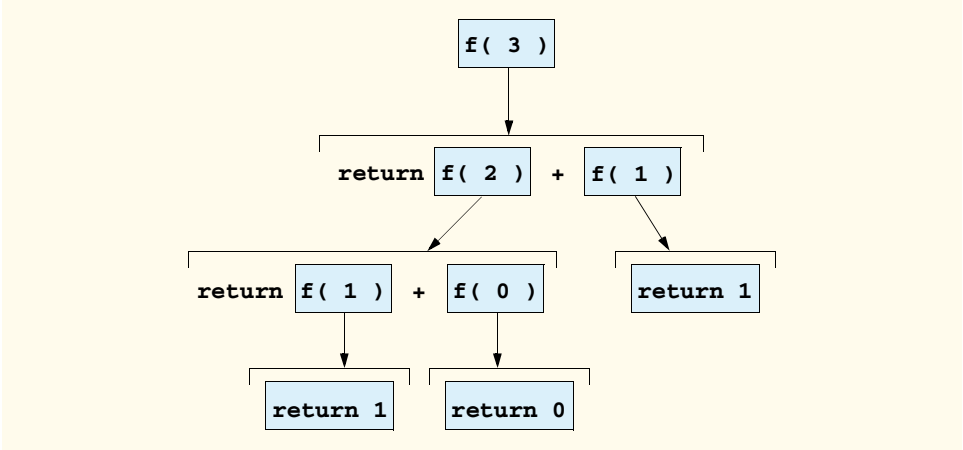

Fig. 6.14 Set of recursive calls to method **fibonacci** (**f** in this diagram).

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As you try calculate larger Fibonacci values, you will notice that each consecutive Fibonacci number you ask the applet to calculate results in a substantial increase in calculation time and number of calls to the **fibonacci** method. For example, the Fibonacci value of 31 requires 4,356,617 calls, and the Fibonacci value of 32 requires 7,049,155 calls. As you can see, the number of calls to **fibonacci** is increasing quickly—1,664,080 additional calls between Fibonacci values of 30 and 31 and 2,692,538 additional calls between Fibonacci values of 31 and 32. This difference in number of calls made between Fibonacci values of 31 and 32 is more than 1.5 times the number of calls for Fibonacci values between 30 and 31. Problems of this nature humble even the world's most powerful computers! In the field of complexity theory, computer scientists study how hard algorithms work to complete their tasks. Complexity issues are discussed in detail in the upper-level computer science curriculum course generally called "Algorithms."

Performance Tip 6.3

Avoid Fibonacci-style recursive programs, which result in an exponential "explosion" of calls.

Testing and Debugging Tip 6.3

Try enhancing the Fibonacci program of Fig. 6.13 such that it calculates the approximate amount of time required to perform the calculation. For this purpose, call ***static System*** *method* ***getCurrentTimeMillis****, which takes no arguments and returns the computer's current time in milliseconds. Call this method twice—once before the call to* ***fibonacci*** *and once after the call to* ***fibonacci****. Save each of these values and calculate the difference in the times to determine how many milliseconds were required to perform the calculation. Display this result.*

6.14 Recursion vs. Iteration

In the previous sections, we studied two methods that can easily be implemented either recursively or iteratively. In this section,we compare the two approaches and discuss why the programmer might choose one approach over the other in a particular situation.

Both iteration and recursion are based on a control structure: Iteration uses a repetition structure (such as **for**, **while** or **do/while**); recursion uses a selection structure (such as **if**, **if/else** or **switch**). Both iteration and recursion involve repetition: Iteration explicitly uses a repetition structure; recursion achieves repetition through repeated method calls. Iteration and recursion each involve a termination test: Iteration terminates when the loop-continuation condition fails; recursion terminates when a base case is recognized. Iteration with counter-controlled repetition and recursion each gradually approach termination: Iteration keeps modifying a counter until the counter assumes a value that makes the loop-continuation condition fail; recursion keeps producing simpler versions of the original problem until the base case is reached. Both iteration and recursion can occur infinitely: An infinite loop occurs with iteration if the loop-continuation test never becomes false; infinite recursion occurs if the recursion step does not reduce the problem each time in a manner that converges on the base case.

Recursion has many negatives. It repeatedly invokes the mechanism and, consequently the overhead, of method calls. This repetition can be expensive in terms of both processor time and memory space. Each recursive call causes another copy of the method (actually, only the method's variables) to be created; this set of copies can consume considerable

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memory space. Iteration normally occurs within a method, so the overhead of repeated method calls and extra memory assignment is omitted. So why choose recursion?

Software Engineering Observation 6.10

Any problem that can be solved recursively can also be solved iteratively (nonrecursively). A recursive approach is normally preferred over an iterative approach when the recursive approach more naturally mirrors the problem and results in a program that is easier to understand and debug. Often, a recursive approach can be implemented with few lines of code and a corresponding iterative approach may take large amounts of code. Another reason to choose a recursive solution is that an iterative solution may not be apparent.

Performance Tip 6.4

Avoid using recursion in situations requiring performance. Recursive calls take time and consume additional memory.

Common Programming Error 6.16

Accidentally having a nonrecursive method call itself either directly or indirectly through another method can cause infinite recursion.

Most programming textbooks introduce recursion much later than we have done here. We feel that recursion is a sufficiently rich and complex topic that it is better to introduce it earlier and spread examples of it over the remainder of the text. Figure 6.15 summarizes the recursion examples and exercises in this text.

Chapter	Recursion examples and exercises
6	Factorial method Fibonacci method Greatest common divisor Sum of two integers Multiply two integers Raising an integer to an integer power Towers of Hanoi Visualizing recursion
7	Sum the elements of an array Print an array Print an array backward Check if a string is a palindrome Minimum value in an array Selection sort Eight Queens Linear search Binary search Quicksort Maze traversal
10	Printing a string input at the keyboard backward

Fig. 6.15 Summary of recursion examples and exercises in this text (part 1 of 2).

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Chapter	Recursion examples and exercises
19	Linked-list insert Linked-list delete Search a linked list Print a linked list backward Binary-tree insert Preorder traversal of a binary tree Inorder traversal of a binary tree Postorder traversal of a binary tree

Fig. 6.15 Summary of recursion examples and exercises in this text (part 2 of 2).

Let us reconsider some observations we make repeatedly throughout this book. Good software engineering is important. High performance is often important. Unfortunately, these goals are often at odds with one another. Good software engineering is key to making more manageable the task of developing larger and more complex software systems. High performance in these systems is key to realizing the systems of the future, which will place ever greater computing demands on hardware. Where do methods fit in here?

Software Engineering Observation 6.11

Modularizing programs in a neat, hierarchical manner promotes good software engineering. But it has a price.

Performance Tip 6.5

A heavily modularized program—as compared with a monolithic (i.e., one-piece) program without methods—makes potentially large numbers of method calls, which consume execution time and space on a computer's processor(s). But monolithic programs are difficult to program, test, debug, maintain and evolve.

So modularize your programs judiciously, always keeping in mind the delicate balance between performance and good software engineering.

6.15 Method Overloading

Java enables several methods of the same name to be defined, as long as the methods have different sets of parameters (based on the number of parameters, the types of the parameters and the order of the parameters). This characteristic is called *method overloading*. When an overloaded method is called, the Java compiler selects the proper method by examining the number, types and order of the arguments in the call. Method overloading is commonly used to create several methods with the same name that perform similar tasks, but on different data types.

Good Programming Practice 6.9

Overloading methods that perform closely related tasks can make programs more readable and understandable.

Figure 6.16 uses overloaded method **`square`** to calculate the square of an **`int`** and the square of a **`double`**.

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```
1  // Fig. 6.16: MethodOverload.java
2  // Using overloaded methods
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class MethodOverload extends JApplet {
11
12    // set up GUI and call versions of method square
13    public void init()
14    {
15       JTextArea outputArea = new JTextArea();
16       Container container = getContentPane();
17       container.add( outputArea );
18
19       outputArea.setText(
20          "The square of integer 7 is " + square( 7 ) +
21          "\nThe square of double 7.5 is " + square( 7.5 ) );
22    }
23
24    // square method with int argument
25    public int square( int intValue )
26    {
27       System.out.println(
28          "Called square with int argument: " + intValue );
29
30       return intValue * intValue;
31
32    }  // end method square with int argument
33
34    // square method with double argument
35    public double square( double doubleValue )
36    {
37       System.out.println(
38          "Called square with double argument: " + doubleValue );
39
40       return doubleValue * doubleValue;
41
42    }  // end method square with double argument
43
44 }  // end class MethodOverload
```

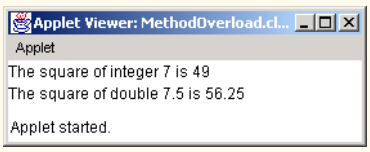

Fig. 6.16 Using overloaded methods (part 1 of 2).

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```
Called square with int argument: 7
Called square with double argument: 7.5
```

Fig. 6.16 Using overloaded methods (part 2 of 2).

Overloaded methods are distinguished by their *signature*—a combination of the method's name and its parameter types. If the Java compiler looked only at method names during compilation, the code in Fig. 6.16 would be ambiguous—the compiler would not know how to distinguish between the two **square** methods. Logically, the compiler uses longer "mangled" or "decorated" names that include the original method name, the types of each parameter and the exact order of the parameters to determine if the methods in a class are unique in that class.

For example, in Fig. 6.16, the compiler might use the logical name "square of int" for the **square** method that specifies an **int** parameter and "square of double" for the **square** method that specifies a **double** parameter. If a method **foo**'s definition begins as

```
void foo( int a, float b )
```

then the compiler might use the logical name "foo of int and float." If the parameters are specified as

```
void foo( float a, int b )
```

then the compiler might use the logical name "foo of float and int." Note that the order of the parameters is important to the compiler. The preceding two **foo** methods are considered to be distinct by the compiler.

The logical names of methods used by the compiler did not mention the return types of the methods, because methods cannot be distinguished by return type. The program in Fig. 6.17 illustrates the compiler errors generated when two methods have the same signature and different return types. Overloaded methods can have different return types, but must have different parameter lists. Also, overloaded methods need not have the same number of parameters.

Common Programming Error 6.17

Creating overloaded methods with identical parameter lists and different return types is a syntax error.

```
1  // Fig. 6.17: MethodOverload.java
2  // Overloaded methods with identical signatures and
3  // different return types.
4
5  // Java extension packages
6  import javax.swing.JApplet;
7
```

Fig. 6.17 Compiler error messages generated from overloaded methods with identical parameter lists and different return types (part 1 of 2).

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```
 8  public class MethodOverload extends JApplet {
 9
10     // first definition of method square with double argument
11     public int square( double x )
12     {
13        return x * x;
14     }
15
16     // second definition of method square with double argument
17     // causes syntax error
18     public double square( double y )
19     {
20        return y * y;
21     }
22
23  }  // end class MethodOverload
```

```
MethodOverload.java:18: square(double) is already defined in
MethodOverload
   public double square( double y )
                 ^
MethodOverload.java:13: possible loss of precision
found   : double
required: int
      return x * x;
               ^
2 errors
```

Fig. 6.17 Compiler error messages generated from overloaded methods with identical parameter lists and different return types (part 2 of 2).

6.16 Methods of Class `JApplet`

We have written many applets to this point in the text, but we have not yet discussed the key methods of class **`JApplet`** that the applet container calls during the execution of an applet. Figure 6.18 lists the key methods of class **`JApplet`**, specifies when they get called and explains the purpose of each method.

These **`JApplet`** methods are defined by the Java API to do nothing unless you provide a definition in your applet's class definition. If you would like to use one of these methods in an applet you are defining, you *must* define the first line of each method as shown in Fig. 6.18. Otherwise, the applet container will not call your versions of the methods during the applet's execution. Defining the methods as discussed here is known as *overriding* the original method definition. The applet container will call the overridden version of a method for your applet before it attempts to call the default versions inherited from **`JApplet`**. Overriding is discussed in detail in Chapter 9.

Common Programming Error 6.18

Providing a definition for one of the ***`JApplet`*** *methods* ***`init`***, ***`start`***, ***`paint`***, ***`stop`*** *or* ***`destroy`*** *that does not match the method headers shown in Figure 6.18 results in a method that will not be called automatically during execution of the applet.*

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Method	When the method is called and its purpose
`public void init()`	This method is called once by the **`appletviewer`** or browser when an applet is loaded for execution. It performs initialization of an applet. Typical actions performed here are initialization of instance variables and GUI components of the applet, loading of sounds to play or images to display (see Chapter 18, Multimedia) and creation of threads (see Chapter 15, Multithreading).
`public void start()`	This method is called after the **`init`** method completes execution and every time the user of the browser returns to the HTML page on which the applet resides (after browsing another HTML page). This method performs any tasks that must be completed when the applet is loaded for the first time into the browser and that must be performed every time the HTML page on which the applet resides is revisited. Typical actions performed here include starting an animation see (Chapter 18, Multimedia) and starting other threads of execution (see Chapter 15, Multithreading).
`public void paint( Graphics g )`	This method is called after the **`init`** method completes execution and the **`start`** method has started executing to draw on the applet. It is also called automatically every time the applet needs to be repainted. For example, if the user covers the applet with another open window on the screen then uncovers the applet, the **`paint`** method is called. Typical actions performed here involve drawing with the **`Graphics`** object **`g`** that is automatically passed to the **`paint`** method for you.
`public void stop()`	This method is called when the applet should stop executing—normally, when the user of the browser leaves the HTML page on which the applet resides. This method performs any tasks that are required to suspend the applet's execution. Typical actions performed here are to stop execution of animations and threads.
`public void destroy()`	This method is called when the applet is being removed from memory—normally, when the user of the browser exits the browsing session. This method performs any tasks that are required to destroy resources allocated to the applet.

Fig. 6.18 **`JApplet`** methods that the applet container calls during an applet's execution .

Method ***`repaint`*** is also of interest to many applet programmers. The applet's **`paint`** method normally is called by the applet container. What if you would like to change the appearance of the applet in response to the user's interactions with the applet? In such situations, you may want to call **`paint`** directly. However, to call **`paint`**, we must pass it the **`Graphics`** parameter it expects. This requirement poses a problem for us. We do not have a **`Graphics`** object at our disposal to pass to **`paint`**. (We discuss this issue in Chapter 18, Multimedia.) For this reason, class **`JApplet`** provides method **`repaint`**. The statement

```
repaint();
```

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obtains the **Graphics** object for you and invokes another method, called ***update***. Method **update** invokes method **paint** and passes to it the **Graphics** object. The **repaint** method is discussed in detail in Chapter 18, "Multimedia."

6.17 (Optional Case Study) Thinking About Objects: Identifying Class Operations

In the "Thinking About Objects" sections at the ends of Chapters 3, 4 and 5, we performed the first few steps in the object-oriented design for our elevator simulator. In Chapter 3, we identified the classes we need to implement. In Chapter 4, we created a class diagram that models the structure of our system. In Chapter 5, we examined objects' states and modeled objects' activities and state transitions.

In this section, we concentrate on determining the class *operations* (or *behaviors*) needed to implement the elevator simulator. In Chapter 7, we concentrate on the collaborations (interactions) between objects of our classes.

An operation of a class is a service that the class provides to "clients" (users) of that class. Consider the operations of some real-world classes. A radio's operations include setting its station and volume (typically invoked by a person adjusting the radio's controls). A car's operations include accelerating (invoked by the driver pressing the accelerator pedal), decelerating (invoked by the driver pressing the brake pedal and/or releasing the gas pedal), turning and shifting gears.

We can derive many of the operations of each class directly from the problem statement. To do so, we examine the verbs and verb phrases in the problem statement. We then relate each of these to particular classes in our system (Fig. 6.20). Many of the verb phrases in Fig. 6.20 help us determine the operations of our classes.

Class	Verb phrases
Elevator	moves to other floor, arrives at a floor, resets elevator button, rings elevator bell, signals its arrival, opens its door, closes its door
ElevatorShaft	turns off light, turns on light, resets floor button
Person	walks on floor, presses floor button, presses elevator button, rides elevator, enters elevator, exits elevator
Floor	[none in the problem statement]
FloorButton	requests elevator
ElevatorButton	closes elevator door, signals elevator to move to opposite floor
FloorDoor	signals person to enter elevator (by opening)
ElevatorDoor	signals person to exit elevator (by opening), opens floor door, closes floor door
Bell	[none in the problem statement]
Light	[none in the problem statement]
ElevatorModel	creates person

Fig. 6.20 Verb phrases for each class in simulator.

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To create operations, we examine the verb phrases listed with each class. The phrase "moves to other floor" listed with class **`Elevator`** refers to the activity in which the elevator moves between floors. Should "moves" be an operation of class **`Elevator`**? The elevator decides to move in response to a button press. A button *signals* the elevator to move, but a button does not actually *move* the elevator—therefore, "moves to other floor" does not correspond to an operation. (We include the operations for informing the elevator to move to the other floor later in the discussion, when we discuss the verb phrases associated with the buttons.) The "arrives at a floor" phrase is also not an operation, because the elevator itself decides when to arrive on the floor after five seconds of travel.

The "resets elevator button" phrase associated with class **`Elevator`** implies that the elevator informs the elevator button to reset. Therefore, class **`ElevatorButton`** needs an operation to provide this service to the elevator. We place this operation (**`resetButton`**) in the bottom compartment of class **`ElevatorButton`** in our class diagram (Fig. 6.21).

We represent the names of the operations as method names (by following the names with a pair of parentheses) and include the return type after the colon:

```
resetButton() : void
```

The parentheses can contain a comma-separated list of the parameters that the operation takes—in this case, none. For the moment, most of our operations have no parameters and a **`void`** return type; this might change as our design and implementation processes proceed.

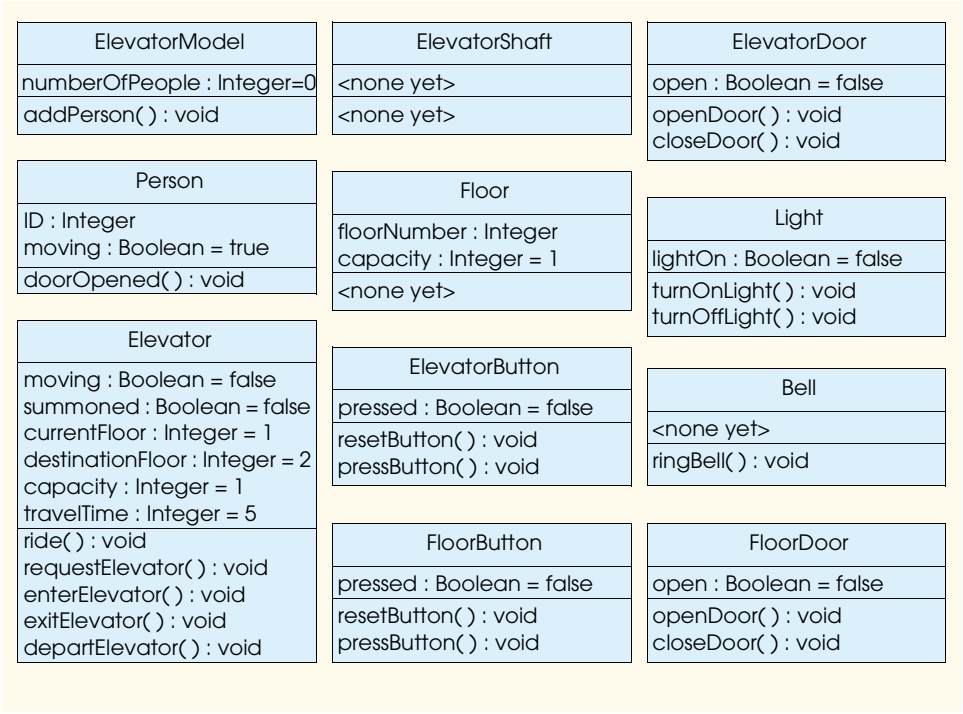

Fig. 6.21 Classes with attributes and operations.

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From the "ring the elevator bell" phrase listed with class **Elevator**, we conclude that class **Bell** should have an operation that provides a service—namely, ringing. We list the **ringBell** operation under class **Bell**.

When arriving at a floor, the elevator "signals its arrival" to the doors. The elevator door responds by opening, as implied by the phrase "opens [the elevator's] door" associated with class **Elevator**. Therefore, class **ElevatorDoor** needs an operation that opens its door. We place the **openDoor** operation in the bottom compartment of this class. The phrase "closes [the elevator's] door" indicates that class **ElevatorDoor** needs an operation that closes its door, so we place the **closeDoor** operation in the same compartment.

Class **ElevatorShaft** lists "turns off light" and "turns on light" in its verb-phrases column, so we create the **turnOffLight** and **turnOnLight** operations and list them under class **Light**. The "resets floor button" phrase implies that the elevator instructs a floor button to reset. Therefore, class **FloorButton** needs a **resetButton** operation.

The phrase "walks on floor" listed by class **Person** is not an operation, because a person decides to walk across the floor in response to that person's creation. However, the phrases "presses floor button" and "presses elevator button" are operations pertaining to the button classes. We therefore place the **pressButton** operation under classes **FloorButton** and **ElevatorButton** in our class diagram (Fig. 6.21). The phrase "rides elevator" implies that **Elevator** needs a method that allows a person to ride the elevator, so we place operation **ride** in the bottom compartment of **Elevator**. The "enters elevator" and "exits elevator" phrases listed with class **Person** suggest that class **Elevator** needs operations that correspond to these actions.[1] We place operations **enterElevator** and **exitElevator** in the bottom compartment of class **Elevator**.

The "requests elevator" phrase listed under class **FloorButton** implies that class **Elevator** needs a **requestElevator** operation. The phrase "signals elevator to move to opposite floor" listed with class **ElevatorButton** implies that **ElevatorButton** informs **Elevator** to depart. Therefore, the **Elevator** needs to provide a "departure" service; we place a **departElevator** operation in the bottom compartment of **Elevator**.

The phrases listed with classes **FloorDoor** and **ElevatorDoor** mention that the doors—by opening—signal a **Person** object to enter or exit the elevator. Specifically, a door informs a person that the door has opened. (The person then enters or exits the elevator, accordingly.) We place the **doorOpened** operation in the bottom compartment for class **Person**. In addition, the **ElevatorDoor** opens and closes the **FloorDoor**, so we assign **openDoor** and **closeDoor** to the bottom compartment of class **FloorDoor**.

Lastly, the "creates person" action associated with class **ElevatorModel** refers to creating a **Person** object and adding it to the simulation. Although we can require **ElevatorModel** to send a "create person" and an "add person" message, an object of class **Person** cannot respond to these messages, because that object does not yet exist. We discuss new objects when we consider implementation in Chapter 8. We place the operation **addPerson** in the bottom compartment of **ElevatorModel** in the class diagram of Fig. 6.21 and anticipate that the application user will invoke this operation.

1. At this point, we can only guess what these operations do. For example, perhaps these operations model real-world elevators, some of which have sensors that detect when passengers enter and exit. For now, we simply list these operations. We will discover what, if any, actions these operations perform as we continue our design process.

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For now, we do not concern ourselves with operation parameters or return types; we attempt to gain only a basic understanding of the operations of each class. As we continue our design process, the number of operations belonging to each class may vary—we might find that new operations are needed or that some current operations are unnecessary—and we might determine that some of our class operations need non-**void** return types.

SUMMARY

- The best way to develop and maintain a large program is to divide it into several smaller modules. Modules are written in Java as classes and methods.
- A method is invoked by a method call. The method call mentions the method by name and provides arguments in parentheses that the called method requires to perform its task. If the method is in another class, the call must be preceded by a reference name and a dot operator. If the method is **static**, it must be preceded by a class name and a dot operator.
- Each argument of a method may be a constant, a variable or an expression.
- A local variable is known only in a method definition. Methods are not allowed to know the implementation details of any other method (including its local variables).
- The on-screen display area for a **JApplet** has a content pane to which the GUI components must be attached so they can be displayed at execution time. The content pane is an object of class **Container** from the **java.awt** package.
- Method **getContentPane** of class **JApplet** returns a reference to the applet's content pane.
- The general format for a method definition is

  return-value-type method-name **(** *parameter-list* **)**
  {
  declarations and statements
  }

  The *return-value-type* states the type of the value returned to the calling method. If a method does not return a value, the *return-value-type* is **void**. The *method-name* is any valid identifier. The *parameter-list* is a comma-separated list containing the declarations of the variables that will be passed to the method. If a method does not receive any values, *parameter-list* is empty. The method body is the set of *declarations and statements* that constitute the method.
- The arguments passed to a method should match in number, type and order with the parameters in the method definition.
- When a program encounters a method, control transfers from the point of invocation to the called method, the method executes and control returns to the caller.
- A called method can return control to the caller in one of three ways. If the method does not return a value, control returns at the method-ending right brace or by executing the statement

  return;

  If the method does return a value, the statement

  return *expression***;**

  returns the value of *expression*.
- There are three ways to call a method—the method name by itself, a reference to an object followed by the dot (**.**) operator and the method name, and a class name followed by the dot (**.**) operator and a method name. The last syntax is for **static** methods of a class.

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- An important feature of method definitions is the coercion of arguments. In many cases, argument values that do not correspond precisely to the parameter types in the method definition are converted to the proper type before the method is called. In some cases, these conversions can lead to compiler errors if Java's promotion rules are not followed.
- The promotion rules specify how types can be converted to other types without losing data. The promotion rules apply to mixed-type expressions. The type of each value in a mixed-type expression is promoted to the "highest" type in the expression.
- Method **Math.random** generates a double value from 0.0 up to, but not including, 1.0. Values produced by **Math.random** can be scaled and shifted to produce values in a range.
- The general equation for scaling and shifting a random number is

```
n = a + (int) ( Math.random() * b );
```

  where **a** is the shifting value (the first number in the desired range of consecutive integers) and **b** is the scaling factor (the width of the desired range of consecutive integers).
- A class can inherit existing attributes and behaviors (data and methods) from another class specified to the right of keyword **extends** in the class definition. In addition, a class can implement one or more *interfaces*. An interface specifies one or more behaviors (i.e., methods) that you must define in your class definition.
- The interface **ActionListener** specifies that a class must define a method with the first line

```
public void actionPerformed( ActionEvent actionEvent )
```

- The task of method **actionPerformed** is to process a user's interaction with a GUI component that generates an action event. This method is called in response to the user interaction (the event). This process is called *event handling*. The event handler is the **actionPerformed** method, which is called in response to the event. This style of programming is known as *event-driven programming*.
- Keyword **final** declares constant variables. Constant variables must be initialized before they are used in a program. Constant variables are often called *named constants* or *read-only variables*.
- A **JLabel** contains a string of characters to be displayed on the screen. Normally, a **JLabel** indicates the purpose of another GUI element on the screen.
- **JTextField**s get information from the user or displays information on the screen.
- When the user presses a **JButton**, the program normally responds by performing a task.
- **Container** method **setLayout** defines the layout manager for the applet's user interface. Layout managers are provided to arrange GUI components on a **Container** for presentation purposes.
- **FlowLayout** is the simplest layout manager. GUI components are placed on a **Container** from left to right in the order in which they are attached to the **Container** with method **add**. When the edge of the container is reached, components are continued on the next line.
- Before any event can be processed, each GUI component must know which object in the program defines the event-handling method that will be called when an event occurs. Method **addActionListener** is used to tell a **JButton** or **JTextField** that another object is listening for action events and defines method **actionPerformed**. This procedure is called *registering the event handler with the GUI component*. To respond to an action event, we must define a class that implements **ActionListener** and defines method **actionPerformed**. Also, we must register the event handler with the GUI component.
- Method **showStatus** displays a **String** in the applet container's status bar.

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- Each variable identifier has the attributes duration (lifetime) and scope. An identifier's duration determines when that identifier exists in memory. An identifier's scope is where the identifier can be referenced in a program.
- Identifiers that represent local variables in a method have automatic duration. Automatic-duration variables are created when program control reaches their declaration; they exist while the block in which they are declared is active; and they are destroyed when the block in which they are declared is exited.
- Java also has identifiers of static duration. Variables and references of static duration exist from the point at which the class in which they are defined is loaded into memory for execution until the program terminates.
- The scopes for an identifier are class scope and block scope. An instance variable declared outside any method has class scope. Such an identifier is "known" in all methods of the class. Identifiers declared inside a block have block scope. Block scope ends at the terminating right brace (`}`) of the block.
- Local variables declared at the beginning of a method have block scope, as do method parameters, which are considered to be local variables of the method.
- Any block may contain variable declarations.
- A recursive method is a method that calls itself, either directly or indirectly.
- If a recursive method is called with a base case, the method returns a result. If the method is called with a more complex problem, the method divides the problem into two or more conceptual pieces: A piece that the method knows how to do and a slightly smaller version of the original problem. Because this new problem looks like the original problem, the method launches a recursive call to work on the smaller problem.
- For recursion to terminate, the sequence of smaller and smaller problems must converge to the base case. When the method recognizes the base case, the result is returned to the previous method call, and a sequence of returns ensues all the way up the line until the original call of the method returns the final result.
- Both iteration and recursion are based on a control structure: Iteration uses a repetition structure; recursion uses a selection structure.
- Both iteration and recursion involve repetition: Iteration explicitly uses a repetition structure; recursion achieves repetition through repeated method calls.
- Iteration and recursion each involve a termination test: Iteration terminates when the loop-continuation condition fails; recursion terminates when a base case is recognized.
- Iteration and recursion can occur infinitely: An infinite loop occurs with iteration if the loop-continuation test never becomes false; infinite recursion occurs if the recursion step does not reduce the problem in a manner that converges to the base case.
- Recursion repeatedly invokes the mechanism and, consequently the overhead, of method calls. This repetition can be expensive in terms of both processor time and memory space.
- The user presses the *Enter* key while typing in a **`JTextField`** to generate an action event. The event handling for this GUI component is set up like a **`JButton`**: Aclass must be defined that implements **`ActionListener`** and defines method **`actionPerformed`**. Also, the **`JTextField`**'s **`addActionListener`** method must be called to register the event.
- It is possible to define methods with the same name, but different parameter lists. This feature is called method overloading. When an overloaded method is called, the compiler selects the proper method by examining the arguments in the call.
- Overloaded methods can have different return values and must have different parameter lists. Two methods differing only by return type will result in a syntax error.

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- The applet's **`init`** method is called once by the applet container when an applet is loaded for execution. It performs initialization of an applet. The applet's **`start`** method is called after the **`init`** method completes execution and every time the user of the browser returns to the HTML page on which the applet resides (after browsing another HTML page).
- The applet's **`paint`** method is called after the **`init`** method completes execution and the **`start`** method has started executing to draw on the applet. It is also called every time the applet needs to be repainted.
- The applet's **`stop`** method is called when the applet should suspend execution—normally, when the user of the browser leaves the HTML page on which the applet resides.
- The applet's **`destroy`** method is called when the applet is being removed from memory—normally, when the user of the browser exits the browsing session.
- Method **`repaint`** can be called in an applet to cause a fresh call to **`paint`**. Method **`repaint`** invokes another method called **`update`** and passes it the **`Graphics`** object. The **`update`** method invokes the **`paint`** method and passes it the **`Graphics`** object.

TERMINOLOGY

`ActionEvent` class
`ActionListener` interface
`actionPerformed` method
argument in a method call
automatic duration
automatic variable
base case in recursion
block
block scope
call a method
called method
caller
calling method
class
class scope
coercion of arguments
constant variable
copy of a value
`destroy` method of **`JApplet`**
divide and conquer
duration
element of chance
factorial method
`final`
`FlowLayout` class
`init` method of **`JApplet`**
invoke a method
iteration
Java API (Java class library)
`JButton` class of package **`javax.swing`**
`JLabel` class of package **`javax.swing`**
`JTextField` class of package **`javax.swing`**
local variable
`Math` class methods
`Math.E`
`Math.PI`
`Math.random` method
method
method call
method-call operator, **`()`**
method declaration
method definition
method overloading
mixed-type expression
modular program
named constant
overloading
`paint` method of **`JApplet`**
parameter in a method definition
programmer-defined method
promotion rules
random-number generation
read-only variable
recursion
recursion step
recursive call
recursive method
reference parameter
reference types
`repaint` method of **`JApplet`**
return
return-value type
scaling
scope
`setLayout` method of **`JApplet`**
shifting

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showStatus method of **JApplet**
signature
simulation
software engineering
software reusability
start method of **JApplet**
static storage duration
stop method of **JApplet**
update method of **JApplet**
void

SELF-REVIEW EXERCISES

6.1 Fill in the blanks in each of the following statements:

a) Program modules in Java are called _____ and_____.
b) A method is invoked with a _____.
c) A variable known only within the method in which it is defined is called a _____.
d) The _____ statement in a called method can be used to pass the value of an expression back to the calling method.
e) The keyword _____ indicates that a method does not return a value.
f) The _____ of an identifier is the portion of the program in which the identifier can be used.
g) The three ways to return control from a called method to a caller are _____, _____ and _____.
h) The _____ method is invoked once when an applet begins execution.
i) The _____ method produces random numbers.
j) The _____ method is invoked each time the user of a browser revisits the HTML page on which an applet resides.
k) The _____ method is invoked to draw on an applet.
l) Variables declared in a block or in a method's parameter list are of _____ duration.
m) The _____ method invokes the applet's **update** method, which in turn invokes the applet's **paint** method.
n) The _____ method is invoked for an applet each time the user of a browser leaves an HTML page on which the applet resides.
o) A method that calls itself either directly or indirectly is a _____ method.
p) A recursive method typically has two components: one that provides a means for the recursion to terminate by testing for a _____ case and one that expresses the problem as a recursive call for a slightly simpler problem than does the original call.
q) In Java, it is possible to have various methods with the same name that each operate on different types and/or numbers of arguments. This feature is called method _____.
r) The _____ qualifier is used to declare read-only variables.

6.2 For the following program, state the scope (either class scope or block scope) of each of the following elements:

a) the variable **x**.
b) the variable **y**.
c) the method **cube**.
d) the method **paint**.
e) the variable **yPos**.

```
1  public class CubeTest extends JApplet {
2     int x;
3
4     public void paint( Graphics g )
5     {
6        int yPos = 25;
```

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```
 7
 8          for ( x = 1; x <= 10; x++ ) {
 9             g.drawString( cube( x ), 25, yPos );
10             yPos += 15;
11          }
12       }
13
14       public int cube( int y )
15       {
16          return y * y * y;
17       }
18    }
```

6.3 Write an application that tests if the examples of the math-library method calls shown in Fig. 6.2 actually produce the indicated results.

6.4 Give the method header for each of the following methods:

a) Method **hypotenuse**, which takes two double-precision, floating-point arguments **side1** and **side2** and returns a double-precision, floating-point result.

b) Method **smallest**, which takes three integers **x**, **y** and **z** and returns an integer.

c) Method **instructions**, which does not take any arguments and does not return a value. [*Note*: Such methods are commonly used to display instructions to a user.]

d) Method **intToFloat**, which takes an integer argument **number** and returns a floating-point result.

6.5 Find the error in each of the following program segments. Explain how to correct the error.

a)
```
int g() {
   System.out.println( "Inside method g" );
   int h() {
      System.out.println( "Inside method h" );
   }
}
```

b)
```
int sum( int x, int y ) {
   int result;
   result = x + y;
}
```

c)
```
int sum( int n ) {
   if ( n == 0 )
      return 0;
   else
      n + sum( n - 1 );
}
```

d)
```
void f( float a ); {
   float a;
   System.out.println( a );
}
```

e)
```
void product() {
   int a = 6, b = 5, c = 4, result;
   result = a * b * c;
   System.out.println( "Result is " + result );
   return result;
}
```

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6.6 Write a complete Java applet to prompt the user for the **double** radius of a sphere, and call method **sphereVolume** to calculate and display the volume of that sphere using the assignment

```
volume = ( 4.0 / 3.0 ) * Math.PI * Math.pow( radius, 3 )
```

The user should input the radius through a **JTextField**.

ANSWERS TO SELF-REVIEW EXERCISES

6.1 a) methods and classes. b) method call. c) local variable. d) **return**. e) **void**. f) scope. g) **return;** or **return** *expression***;** or encountering the closing right brace of a method. h) **init**. i) **Math.random**. j) **start**. k) **paint**. l) automatic. m) **repaint**. n) **stop**. o) recursive. p) base. q) overloading. r) **final**.

6.2 a) Class scope. b) Block scope. c) Class scope. d) Class scope. e) Block scope.

6.3 The following solution demonstrates the **Math** class methods in Fig. 6.2:

```
1  // Exercise 6.3: MathTest.java
2  // Testing the Math class methods
3
4  public class MathTest {
5     public static void main( String args[] )
6     {
7        System.out.println( "Math.abs( 23.7 ) = " +
8                            Math.abs( 23.7 ) );
9        System.out.println( "Math.abs( 0.0 ) = " +
10                           Math.abs( 0.0 ) );
11       System.out.println( "Math.abs( -23.7 ) = " +
12                           Math.abs( -23.7 ) );
13       System.out.println( "Math.ceil( 9.2 ) = " +
14                           Math.ceil( 9.2 ) );
15       System.out.println( "Math.ceil( -9.8 ) = " +
16                           Math.ceil( -9.8 ) );
17       System.out.println( "Math.cos( 0.0 ) = " +
18                           Math.cos( 0.0 ) );
19       System.out.println( "Math.exp( 1.0 ) = " +
20                           Math.exp( 1.0 ) );
21       System.out.println( "Math.exp( 2.0 ) = " +
22                           Math.exp( 2.0 ) );
23       System.out.println( "Math.floor( 9.2 ) = " +
24                           Math.floor( 9.2 ) );
25       System.out.println( "Math.floor( -9.8 ) = " +
26                           Math.floor( -9.8 ) );
27       System.out.println( "Math.log( 2.718282 ) = " +
28                           Math.log( 2.718282 ) );
29       System.out.println( "Math.log( 7.389056 ) = " +
30                           Math.log( 7.389056 ) );
31       System.out.println( "Math.max( 2.3, 12.7 ) = v +
32                           Math.max( 2.3, 12.7 ) );
33       System.out.println( "Math.max( -2.3, -12.7 ) = " +
34                           Math.max( -2.3, -12.7 ) );
35       System.out.println( "Math.min( 2.3, 12.7 ) = " +
36                           Math.min( 2.3, 12.7 ) );
37       System.out.println( "Math.min( -2.3, -12.7 ) = " +
38                           Math.min( -2.3, -12.7 ) );
```

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```
39         System.out.println( "Math.pow( 2, 7 ) = " +
40                             Math.pow( 2, 7 ) );
41         System.out.println( "Math.pow( 9, .5 ) = " +
42                             Math.pow( 9, .5 ) );
43         System.out.println( "Math.sin( 0.0 ) = " +
44                             Math.sin( 0.0 ) );
45         System.out.println( "Math.sqrt( 25.0 ) = " +
46                             Math.sqrt( 25.0 ) );
47         System.out.println( "Math.tan( 0.0 ) = " +
48                             Math.tan( 0.0 ) );
49      }
50   }
```

```
Math.abs( 23.7 ) = 23.7
Math.abs( 0.0 ) = 0
Math.abs( -23.7 ) = 23.7
Math.ceil( 9.2 ) = 10
Math.ceil( -9.8 ) = -9
Math.cos( 0.0 ) = 1
Math.exp( 1.0 ) = 2.71828
Math.exp( 2.0 ) = 7.38906
Math.floor( 9.2 ) = 9
Math.floor( -9.8 ) = -10
Math.log( 2.718282 ) = 1
Math.log( 7.389056 ) = 2
Math.max( 2.3, 12.7 ) = 12.7
Math.max( -2.3, -12.7 ) = -2.3
Math.min( 2.3, 12.7 ) = 2.3
Math.min( -2.3, -12.7 ) = -12.7
Math.pow( 2, 7 ) = 128
Math.pow( 9, .5 ) = 3
Math.sin( 0.0 ) = 0
Math.sqrt( 25.0 ) = 5
Math.tan( 0.0 ) = 0
```

6.4 a) `double hypotenuse( double side1, double side2 )`
b) `int smallest( int x, int y, int z )`
c) `void instructions()`
d) `float intToFloat( int number )`

6.5 a) Error: Method **h** is defined in method **g**.
Correction: Move the definition of **h** outside the definition of **g**.

b) Error: The method is supposed to return an integer, but does not.
Correction: Delete variable **result**, and place the statement

```
return x + y;
```

in the method, or add the following statement at the end of the method body:

```
return result;
```

c) Error: The result of **n + sum(n - 1)** is not returned by this recursive method, resulting in a syntax error.
Correction: Rewrite the statement in the **else** clause as

```
return n + sum( n - 1 );
```

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d) Error: Both the semicolon after the right parenthesis that encloses the parameter list and redefining the parameter **a** in the method definition are incorrect.
Correction: Delete the semicolon after the right parenthesis of the parameter list, and delete the declaration **float a;**.

e) Error: The method returns a value when it is not supposed to.
Correction: Change the return type to **int**.

6.6 The following solution calculates the volume of a sphere using the radius entered by the user:

```
1  // Exercise 6.6: SphereTest.java
2
3  // Java core packages
4  import java.awt.*;
5  import java.awt.event.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class SphereTest extends JApplet
11    implements ActionListener {
12
13    JLabel promptLabel;
14    JTextField inputField;
15
16    public void init()
17    {
18       Container container = getContentPane();
19       container.setLayout( new FlowLayout() );
20
21       promptLabel = new JLabel( "Enter sphere radius: " );
22       inputField = new JTextField( 10 );
23       inputField.addActionListener( this );
24       container.add( promptLabel );
25       container.add( inputField );
26    }
27
28    public void actionPerformed( ActionEvent actionEvent )
29    {
30       double radius =
31          Double.parseDouble( actionEvent.getActionCommand() );
32
33       showStatus( "Volume is " + sphereVolume( radius ) );
34    }
35
36    public double sphereVolume( double radius )
37    {
38       double volume =
39          ( 4.0 / 3.0 ) * Math.PI * Math.pow( radius, 3 );
40
41       return volume;
42    }
43 }
```

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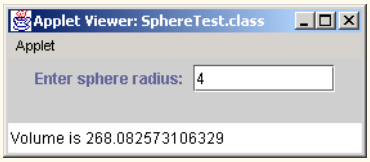

EXERCISES

6.7 What is the value of **x** after each of the following statements is performed?

a) `x = Math.abs( 7.5 );`
b) `x = Math.floor( 7.5 );`
c) `x = Math.abs( 0.0 );`
d) `x = Math.ceil( 0.0 );`
e) `x = Math.abs( -6.4 );`
f) `x = Math.ceil( -6.4 );`
g) `x = Math.ceil( -Math.abs( -8 + Math.floor( -5.5 ) ) );`

6.8 A parking garage charges a $2.00 minimum fee to park for up to three hours. The garage charges an additional $0.50 per hour for each hour *or part thereof* in excess of three hours. The maximum charge for any given 24-hour period is $10.00. Assume that no car parks for longer than 24 hours at a time. Write an applet that calculates and displays the parking charges for each customer who parked a car in this garage yesterday. You should enter in a **`JTextField`** the hours parked for each customer. The program should display the charge for the current customer and should calculate and display the running total of yesterday's receipts. The program should use the method **`calculateCharges`** to determine the charge for each customer.

6.9 An application of method **`Math.floor`** is rounding a value to the nearest integer. The statement

```
y = Math.floor( x + .5 );
```

will round the number **x** to the nearest integer and assign the result to **y**. Write an applet that reads **`double`** values and uses the preceding statement to round each of the numbers to the nearest integer. For each number processed, display both the original number and the rounded number.

6.10 **`Math.floor`** may be used to round a number to a specific decimal place. The statement

```
y = Math.floor( x * 10 + .5 ) / 10;
```

rounds **x** to the tenths position (i.e., the first position to the right of the decimal point). The statement

```
y = Math.floor( x * 100 + .5 ) / 100;
```

rounds **x** to the hundredths position (i.e., the second position to the right of the decimal point). Write an applet that defines four methods to round a number **x** in various ways:

a) `roundToInteger( number )`
b) `roundToTenths( number )`
c) `roundToHundredths( number )`
d) `roundToThousandths( number )`

For each value read, your program should display the original value, the number rounded to the nearest integer, the number rounded to the nearest tenth, the number rounded to the nearest hundredth and the number rounded to the nearest thousandth.

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6.11 Answer each of the following questions:

a) What does it mean to choose numbers "at random?"
b) Why is the **`Math.random`** method useful for simulating games of chance?
c) Why is it often necessary to scale and/or shift the values produced by **`Math.random`**?
d) Why is computerized simulation of real-world situations a useful technique?

6.12 Write statements that assign random integers to the variable *n* in the following ranges:

a) $1 \le n \le 2$
b) $1 \le n \le 100$
c) $0 \le n \le 9$
d) $1000 \le n \le 1112$
e) $-1 \le n \le 1$
f) $-3 \le n \le 11$

6.13 For each of the following sets of integers, write a single statement that will print a number at random from the set:

a) 2, 4, 6, 8, 10.
b) 3, 5, 7, 9, 11.
c) 6, 10, 14, 18, 22.

6.14 Write a method **`integerPower( base, exponent )`** that returns the value of

$$base^{exponent}$$

For example, **`integerPower( 3, 4 )`** calculates 3^4 (or **`3 * 3 * 3 * 3`**). Assume that **`exponent`** is a positive, nonzero integer and that **`base`** is an integer. Method **`integerPower`** should use **`for`** or **`while`** to control the calculation. Do not use any math library methods. Incorporate this method into an applet that reads integer values from **`JTextField`**s for **`base`** and **`exponent`** from the user and performs the calculation with the **`integerPower`** method. [*Note*: Register for event handling on only the second **`JTextField`**. The user should interact with the program by typing numbers in both **`JTextField`**s and pressing *Enter* only in the second **`JTextField`**.]

6.15 Define a method **`hypotenuse`** that calculates the length of the hypotenuse of a right triangle when the other two sides are given (sample data appear in Fig. 6.22). The method should take two arguments of type **`double`** and return the hypotenuse as a **`double`**. Incorporate this method into an applet that reads values for **`side1`** and **`side2`** from **`JTextField`**s and performs the calculation with the **`hypotenuse`** method. Determine the length of the hypotenuse for each of the following triangles. [*Note*: Register for event handling on only the second **`JTextField`**. The user should interact with the program by typing numbers in both **`JTextField`**s and pressing *Enter* only in the second **`JTextField`**.]

Triangle	Side 1	Side 2
1	**`3.0`**	**`4.0`**
2	**`5.0`**	**`12.0`**
3	**`8.0`**	**`15.0`**

Fig. 6.22 Values for the sides of triangles in Exercise 6.15.

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6.16 Write a method **multiple** that determines for a pair of integers whether the second integer is a multiple of the first. The method should take two integer arguments and return **true** if the second is a multiple of the first and **false** otherwise. Incorporate this method into an applet that inputs a series of pairs of integers (one pair at a time using **JTextField**s). [Note: Register for event handling on only the second **JTextField**. The user should interact with the program by typing numbers in both **JTextField**s and pressing *Enter* only in the second **JTextField**.]

6.17 Write a method **isEven** that uses the modulus operator to determine if an integer is even. The method should take an integer argument and return **true** if the integer is even and **false** otherwise. Incorporate this method into an applet that inputs a series integers (one at a time using a **JTextField**).

6.18 Write a method **squareOfAsterisks** that displays a solid square of asterisks whose side is specified in integer parameter **side**. For example, if **side** is **4**, the method displays

```
****
****
****
****
```

Incorporate this method into an applet that reads an integer value for **side** from the user at the keyboard and performs the drawing with the **squareOfAsterisks** method. Note that this method should be called from the applet's **paint** method and should be passed the **Graphics** object from **paint**.

6.19 Modify the method created in Exercise 6.18 to form the square out of whatever character is contained in character parameter **fillCharacter**. Thus, if **side** is **5** and **fillCharacter** is "**#**", the method should print

```
#####
#####
#####
#####
#####
```

6.20 Use techniques similar to those developed in Exercise 6.18 and Exercise 6.19 to produce a program that graphs a wide range of shapes.

6.21 Modify the program of Exercise 6.18 to draw a solid square with the **fillRect** method of the **Graphics** class. Method **fillRect** receives four arguments: *x*-coordinate, *y*-coordinate, width and height. Allow the user to input the coordinates at which the square should appear.

6.22 Write program segments that accomplish each of the following tasks:

a) Calculate the integer part of the quotient when integer **a** is divided by integer **b**.

b) Calculate the integer remainder when integer **a** is divided by integer **b**.

c) Use the program pieces developed in parts a) and b) to write a method **displayDigits** that receives an integer between **1** and **99999** and prints it as a series of digits, each pair of which is separated by two spaces. For example, the integer **4562** should be printed as

```
4  5  6  2
```

d) Incorporate the method developed in part c) into an applet that inputs an integer from an input dialog and invokes **displayDigits** by passing the method the integer entered. Display the results in a message dialog.

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6.23 Implement the following integer methods:

a) Method **celsius** returns the Celsius equivalent of a Fahrenheit temperature, using the calculation

```
C = 5.0 / 9.0 * ( F - 32 );
```

b) Method **fahrenheit** returns the Fahrenheit equivalent of a Celsius temperature, using the calculation

```
F = 9.0 / 5.0 * C + 32;
```

c) Use these methods to write an applet that enables the user to enter either a Fahrenheit temperature and display the Celsius equivalent or enter a Celsius temperature and display the Fahrenheit equivalent.

[*Note*: This applet will require two **JTextField** objects that have registered action events. When **actionPerformed** is invoked, the **ActionEvent** parameter has method **getSource()** to determine the GUI component with which the user interacted. Your **actionPerformed** method should contain an **if/else** structure of the form

```
if ( actionEvent.getSource() == input1 ) {
   // process input1 interaction here
}
else {  // e.getSource() == input2
   // process input2 interaction here
}
```

where **input1** and **input2** are **JTextField** references.]

6.24 Write a method **minimum3** that returns the smallest of three floating-point numbers. Use the **Math.min** method to implement **minimum3**. Incorporate the method into an applet that reads three values from the user and determines the smallest value. Display the result in the status bar.

6.25 An integer number is said to be a *perfect number* if its factors, including 1 (but not the number itself), sum to the number. For example, 6 is a perfect number, because 6 = 1 + 2 + 3. Write a method **perfect** that determines if parameter **number** is a perfect number. Use this method in an applet that determines and displays all the perfect numbers between 1 and 1000. Print the factors of each perfect number to confirm that the number is indeed perfect. Challenge the computing power of your computer by testing numbers much larger than 1000. Display the results in a **JTextArea** that has scrolling functionality.

6.26 An integer is said to be *prime* if it is divisible only by 1 and itself. For example, 2, 3, 5 and 7 are prime, but 4, 6, 8 and 9 are not.

a) Write a method that determines if a number is prime.

b) Use this method in an applet that determines and prints all the prime numbers between 1 and 10,000. How many of these 10,000 numbers do you really have to test before being sure that you have found all the primes? Display the results in a **JTextArea** that has scrolling functionality.

c) Initially, you might think that $n/2$ is the upper limit for which you must test to see if a number is prime, but you need only go as high as the square root of n. Why? Rewrite the program, and run it both ways. Estimate the performance improvement.

6.27 Write a method that takes an integer value and returns the number with its digits reversed. For example, given the number 7631, the method should return 1367. Incorporate the method into an applet that reads a value from the user. Display the result of the method in the status bar.

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6.28 The *greatest common divisor* (*GCD*) of two integers is the largest integer that evenly divides each of the two numbers. Write a method **gcd** that returns the greatest common divisor of two integers. Incorporate the method into an applet that reads two values from the user. Display the result of the method in the status bar.

6.29 Write a method **qualityPoints** that inputs a student's average and returns **4** if a student's average is 90–100, **3** if the average is 80–89, **2** if the average is 70–79, **1** if the average is 60–69 and **0** if the average is lower than 60. Incorporate the method into an applet that reads a value from the user. Display the result of the method in the status bar.

6.30 Write an applet that simulates coin tossing. Let the program toss a coin each time the user presses the "**Toss**" button. Count the number of times each side of the coin appears. Display the results. The program should call a separate method **flip** that takes no arguments and returns **false** for tails and **true** for heads. [*Note*: If the program realistically simulates coin tossing, each side of the coin should appear approximately half the time.]

6.31 Computers are playing an increasing role in education. Write a program that will help an elementary school student learn multiplication. Use **Math.random** to produce two positive one-digit integers. The program should then display a question in the status bar, such as

```
How much is 6 times 7?
```

The student then types the answer into a **JTextField**. Next, the program checks the student's answer. If it is correct, draw the string **"Very good!"** on the applet and ask another multiplication question. If the answer is wrong, draw the string **"No. Please try again."** on the applet and let the student try the same question again repeatedly until the student finally gets it right. A separate method should be used to generate each new question. This method should be called once when the applet begins execution and each time the user answers the question correctly. All drawing on the applet should be performed by the **paint** method.

6.32 The use of computers in education is referred to as *computer-assisted instruction* (*CAI*). One problem that develops in CAI environments is student fatigue. This problem can be eliminated by varying the computer's dialogue to hold the student's attention. Modify the program of Exercise 6.31 so the various comments are printed for each correct answer and each incorrect answer as follows:

Responses to a correct answer

```
Very good!
Excellent!
Nice work!
Keep up the good work!
```

Responses to an incorrect answer

```
No. Please try again.
Wrong. Try once more.
Don't give up!
No. Keep trying.
```

Use random-number generation to choose a number from 1 to 4 that will be used to select an appropriate response to each answer. Use a **switch** structure in the **paint** method to issue the responses.

6.33 More sophisticated computer-aided instruction systems monitor the student's performance over a period of time. The decision to begin a new topic is often based on the student's success with previous topics. Modify the program of Exercise 6.32 to count the number of correct and incorrect

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responses typed by the student. After the student types 10 answers, your program should calculate the percentage of correct responses. If the percentage is lower than 75%, print **`Please ask your instructor for extra help`** and reset the program so another student can try the program.

6.34 Write an applet that plays the "guess the number" game as follows: Your program chooses the number to be guessed by selecting a random integer in the range 1 to 1000. The applet displays the prompt **`Guess a number between 1 and 1000`** next to a **`JTextField`**. The player types a first guess into the **`JTextField`** and presses the *Enter* key. If the player's guess is incorrect, your program should display **`Too high. Try again.`** or **`Too low. Try again.`** in the status bar to help the player "zero in" on the correct answer and should clear the **`JTextField`** so the user can enter the next guess. When the user enters the correct answer, display **`Congratulations. You guessed the number!`** in the status bar and clear the **`JTextField`** so the user can play again. [*Note*: The guessing technique employed in this problem is similar to a *binary search.*]

6.35 Modify the program of Exercise 6.34 to count the number of guesses the player makes. If the number is 10 or fewer, print **`Either you know the secret or you got lucky!`** If the player guesses the number in 10 tries, print **`Aha! You know the secret!`** If the player makes more than 10 guesses, print **`You should be able to do better!`** Why should it take no more than 10 guesses? Well, with each "good guess" the player should be able to eliminate half of the numbers. Now show why any number from 1 to 1000 can be guessed in 10 or fewer tries.

6.36 Write a recursive method **`power( base, exponent )`** that when invoked returns

$$base^{exponent}$$

For example, **`power( 3, 4 ) = 3 * 3 * 3 * 3`**. Assume that **`exponent`** is an integer greater than or equal to 1. (*Hint*: The recursion step should use the relationship

$$base^{exponent} = base \cdot base^{exponent - 1}$$

and the terminating condition occurs when **`exponent`** is equal to **`1`**, because

$$base^{1} = base$$

Incorporate this method into an applet that enables the user to enter the **`base`** and **`exponent`**.)

6.37 *(Towers of Hanoi)* Every budding computer scientist must grapple with certain classic problems, and the *Towers of Hanoi* (see Fig. 6.23) is one of the most famous. Legend has it that in a temple in the Far East, priests are attempting to move a stack of disks from one peg to another. The initial stack has 64 disks threaded onto one peg and arranged from bottom to top by decreasing size. The priests are attempting to move the stack from this peg to a second peg under the constraints that exactly one disk is moved at a time and at no time may a larger disk be placed above a smaller disk. A third peg is available for temporarily holding disks. Supposedly, the world will end when the priests complete their task, so there is little incentive for us to facilitate their efforts.

Let us assume that the priests are attempting to move the disks from peg 1 to peg 3. We wish to develop an algorithm that will print the precise sequence of peg-to-peg disk transfers.

If we were to approach this problem with conventional methods, we would rapidly find ourselves hopelessly knotted up in managing the disks. Instead, if we attack the problem with recursion in mind, it immediately becomes tractable. Moving n disks can be viewed in terms of moving only $n - 1$ disks (and hence the recursion) as follows:

a) Move $n - 1$ disks from peg 1 to peg 2, using peg 3 as a temporary holding area.
b) Move the last disk (the largest) from peg 1 to peg 3.
c) Move the $n - 1$ disks from peg 2 to peg 3, using peg 1 as a temporary holding area.

The process ends when the last task involves moving $n = 1$ disk (i.e., the base case). This task is accomplished by simply moving the disk, without the need for a temporary holding area.

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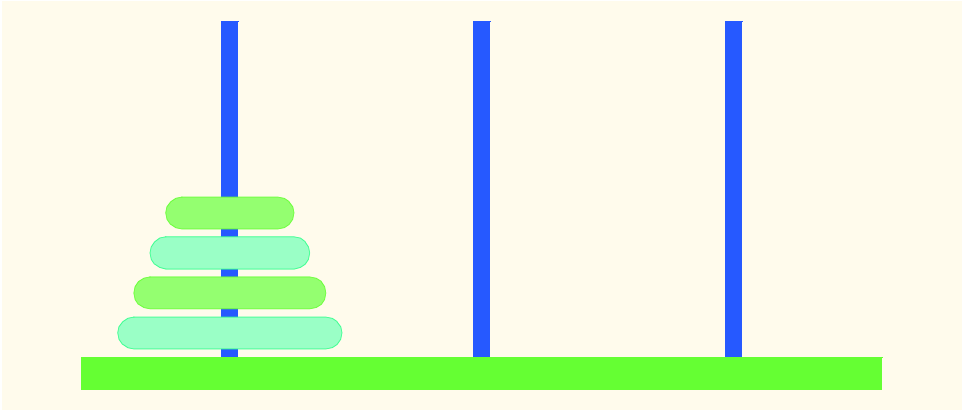

Fig. 6.23 The Towers of Hanoi for the case with four disks.

Write an applet to solve the Towers of Hanoi problem. Allow the user to enter the number of disks in a **`JTextField`**. Use a recursive **`tower`** method with four parameters:

a) the number of disks to be moved,
b) the peg on which these disks are initially threaded,
c) the peg to which this stack of disks is to be moved, and
d) the peg to be used as a temporary holding area.

Your program should display in a **`JTextArea`** with scrolling functionality the precise instructions it will take to move the disks from the starting peg to the destination peg. For example, to move a stack of three disks from peg 1 to peg 3, your program should print the following series of moves:

```
1 → 3 (This notation means move one disk from peg 1 to peg 3.)
1 → 2
3 → 2
1 → 3
2 → 1
2 → 3
1 → 3
```

6.38 Any program that can be implemented recursively can be implemented iteratively, although sometimes with more difficulty and less clarity. Try writing an iterative version of the Towers of Hanoi. If you succeed, compare your iterative version with the recursive version you developed in Exercise 6.37. Investigate issues of performance, clarity and your ability to demonstrate the correctness of the programs.

6.39 (*Visualizing Recursion*) It is interesting to watch recursion "in action." Modify the factorial method of Fig. 6.12 to print its local variable and recursive-call parameter. For each recursive call, display the outputs on a separate line, and add a level of indentation. Do your utmost to make the outputs clear, interesting and meaningful. Your goal here is to design and implement an output format that helps a person understand recursion better. You may want to add such display capabilities to the many other recursion examples and exercises throughout the text.

6.40 The greatest common divisor of integers **`x`** and **`y`** is the largest integer that evenly divides into both **`x`** and **`y`**. Write a recursive method **`gcd`** that returns the greatest common divisor of **`x`** and **`y`**. The **`gcd`** of **`x`** and **`y`** is defined recursively as follows: If **`y`** is equal to **`0`**, then **`gcd( x, y )`** is **`x`**; otherwise, **`gcd( x, y )`** is **`gcd( y, x % y )`**, where **`%`** is the modulus operator. Use this method to replace the one you wrote in the applet of Exercise 6.28.

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6.41 Exercise 6.31 through Exercise 6.33 developed a computer-assisted instruction program to teach an elementary school student multiplication. This exercise suggests enhancements to that program.

a) Modify the program to allow the user to enter a grade-level capability. A grade level of 1 means to use only single-digit numbers in the problems, a grade level of 2 means to use numbers as large as two digits, etc.

b) Modify the program to allow the user to pick the type of arithmetic problems he or she wishes to study. An option of **1** means addition problems only, **2** means subtraction problems only, **3** means multiplication problems only, **4** means division problems only and **5** means to intermix randomly problems of all these types.

6.42 Write method **distance**, to calculate the distance between two points (*x1*, *y1*) and (*x2*, *y2*). All numbers and return values should be of type **double**. Incorporate this method into an applet that enables the user to enter the coordinates of the points.

6.43 What does the following method do?

```
// Parameter b must be a positive
// integer to prevent infinite recursion
public int mystery( int a, int b )
{
   if ( b == 1 )
      return a;
   else
      return a + mystery( a, b - 1 );
}
```

6.44 After you determine what the program in Exercise 6.43 does, modify the method to operate properly after removing the restriction of the second argument being nonnegative. Also, incorporate the method into an applet that enables the user to enter two integers, and test the method.

6.45 Write an application that tests as many of the math-library methods in Fig. 6.2 as you can. Exercise each of the methods by having your program print out tables of return values for a diversity of argument values.

6.46 Find the error in the following recursive method, and explain how to correct it:

```
public int sum( int n )
{
   if ( n == 0 )
      return 0;
   else
      return n + sum( n );
}
```

6.47 Modify the craps program of Fig. 6.9 to allow wagering. Initialize variable **bankBalance** to 1000 dollars. Prompt the player to enter a **wager**. Check that **wager** is less than or equal to **bankBalance**, and if not, have the user reenter **wager** until a valid **wager** is entered. After a correct **wager** is entered, run one game of craps. If the player wins, increase **bankBalance** by **wager**, and print the new **bankBalance**. If the player loses, decrease **bankBalance** by **wager**, print the new **bankBalance**, check if **bankBalance** has become zero, and if so, print the message **"Sorry. You busted!"** As the game progresses, print various messages to create some "chatter," such as **"Oh, you're going for broke, huh?"** or **"Aw c'mon, take a chance!"** or **"You're up big. Now's the time to cash in your chips!"**. Implement the "chatter" as a separate method that randomly chooses the string to display.

6.48 Write an applet that uses a method **circleArea** to prompt the user for the radius of a circle and to calculate and print the area of that circle.

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7

Arrays

Objectives

- To introduce the array data structure.
- To understand the use of arrays to store, sort and search lists and tables of values.
- To understand how to declare an array, initialize an array and refer to individual elements of an array.
- To be able to pass arrays to methods.
- To understand basic sorting techniques.
- To be able to declare and manipulate multiple-subscript arrays.

With sobs and tears he sorted out
Those of the largest size …
Lewis Carroll

Attempt the end, and never stand to doubt;
Nothing's so hard, but search will find it out.
Robert Herrick

Now go, write it before them in a table,
and note it in a book.
Isaiah 30:8

'Tis in my memory lock'd,
And you yourself shall keep the key of it.
William Shakespeare

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Outline

7.1 Introduction
7.2 Arrays
7.3 Declaring and Allocating Arrays
7.4 Examples Using Arrays
7.4.1 Allocating an Array and Initializing Its Elements
7.4.2 Using an Initializer List to Initialize Elements of an Array
7.4.3 Calculating the Value to Store in Each Array Element
7.4.4 Summing the Elements of an Array
7.4.5 Using Histograms to Display Array Data Graphically
7.4.6 Using the Elements of an Array as Counters
7.4.7 Using Arrays to Analyze Survey Results
7.5 References and Reference Parameters
7.6 Passing Arrays to Methods
7.7 Sorting Arrays
7.8 Searching Arrays: Linear Search and Binary Search
7.8.1 Searching an Array with Linear Search
7.8.2 Searching a Sorted Array with Binary Search
7.9 Multiple-Subscripted Arrays
7.10 (Optional Case Study) Thinking About Objects: Collaboration Among Objects

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises • Recursion Exercises • Special Section: Building Your own Computer

7.1 Introduction

This chapter serves as an introduction to the important topic of data structures. *Arrays* are data structures consisting of related data items of the same type. Arrays are "static" entities, in that they remain the same size once they are created, although an array reference may be reassigned to a new array of a different size. Chapter 19, "Data Structures," introduces dynamic data structures, such as lists, queues, stacks and trees, that can grow and shrink as programs execute. Chapter 20, "Java Utilities Package and Bit Manipulation," discusses class **`Vector`**, which is an array-like class whose objects can grow and shrink in response to a Java program's changing storage requirements. Chapter 21, "The Collections API," introduces Java's predefined data structures that enable the programmer to use existing data structures for lists, queues, stacks and trees rather than "reinventing the wheel." The Collections API also provides class **`Arrays`**, which defines a set of utility methods for array manipulation.

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7.2 Arrays

An array is a group of contiguous memory locations that all have the same name and the same type. To refer to a particular location or element in the array, we specify the name of the array and the *position number* (or *index* or *subscript*) of the particular element in the array.

Figure 7.1 shows an integer array called **c**. This array contains 12 *elements*. A program refers to any one of these elements by giving the name of the array followed by the position number of the particular element in square brackets (**[]**). The first element in every array has *position number zero* (sometimes called the *zeroth element*). Thus, the first element of array **c** is **c[0]**, the second element of array **c** is **c[1]**, the seventh element of array **c** is **c[6]**, and, in general, the *i*th element of array **c** is **c[i - 1]**. Array names follow the same conventions as other variable names.

Formally, the position number in square brackets is called a subscript (or an index). A subscript must be an integer or an integer expression. If a program uses an expression as a subscript, the program evaluates the expression to determine the subscript. For example, if we assume that variable **a** is **5** and that variable **b** is **6**, then the statement

```
c[ a + b ] += 2;
```

adds 2 to array element **c[11]**. Note that a subscripted array name is an *lvalue*—it can be used on the left side of an assignment to place a new value into an array element.

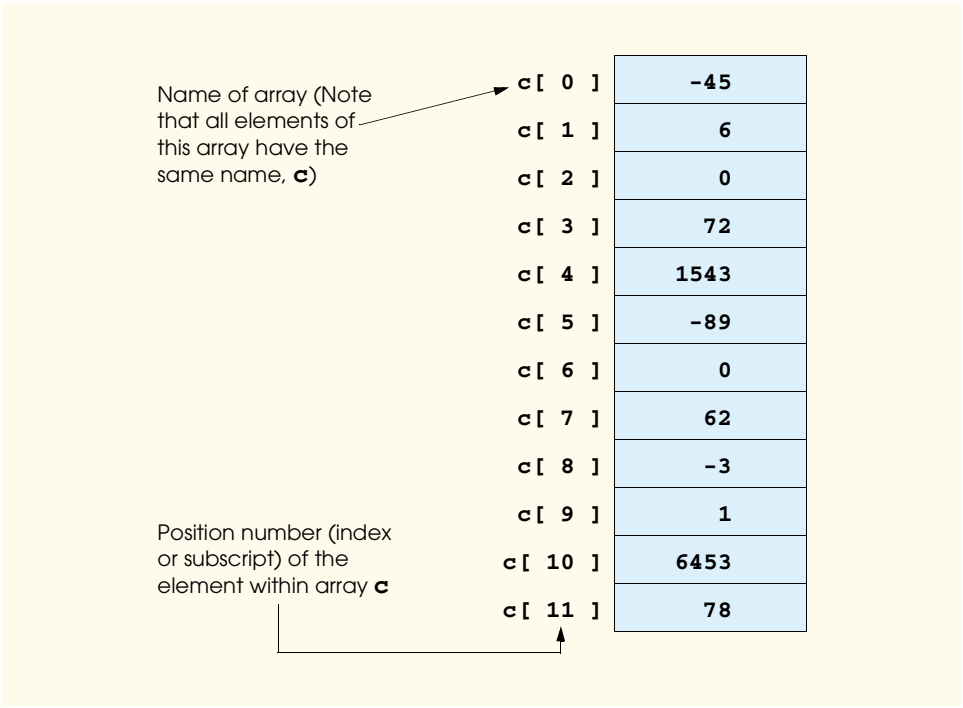

Fig. 7.1 A 12-element array.

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Let us examine array **c** in Figure 7.1 more closely. The *name* of the array is **c**. Every array in Java *knows* its own length and maintains this information in a variable called ***length***. The expression **c.length** accesses array **c**'s **length** variable to determine the length of the array. The array's 12 elements are referred to as **c[0]**, **c[1]**, **c[2]**, …, **c[11]**. The *value* of **c[0]** is **-45**, the value of **c[1]** is **6**, the value of **c[2]** is **0**, the value of **c[7]** is **62** and the value of **c[11]** is **78**. To calculate the sum of the values contained in the first three elements of array **c** and store the result in variable **sum**, we would write

```
sum = c[ 0 ] + c[ 1 ] + c[ 2 ];
```

To divide the value of the seventh element of array **c** by **2** and assign the result to the variable **x**, we would write

```
x = c[ 6 ] / 2;
```

Common Programming Error 7.1

It is important to note the difference between the "seventh element of the array" and "array element seven." Because array subscripts begin at 0, the "seventh element of the array" has a subscript of 6, while "array element seven" has a subscript of 7 and is actually the eighth element of the array. This confusion is a source of "off-by-one" errors.

The brackets used to enclose the subscript of an array are one of Java's many operators. Brackets are in the highest level of precedence in Java. The chart in Fig. 7.2 shows the precedence and associativity of the operators introduced so far. They are shown top to bottom in decreasing order of precedence with their associativity and type. See Appendix C for the complete operator precedence chart.

Operators	Associativity	Type
`() [] .`	left to right	highest
`++ --`	right to left	unary postfix
`++ -- + - ! (`*type*`)`	right to left	unary
`* / %`	left to right	multiplicative
`+ -`	left to right	additive
`< <= > >=`	left to right	relational
`== !=`	left to right	equality
`&`	left to right	boolean logical AND
`^`	left to right	boolean logical exclusive OR
`|`	left to right	boolean logical inclusive OR
`&&`	left to right	logical AND
`||`	left to right	logical OR
`?:`	right to left	conditional
`= += -= *= /= %=`	right to left	assignment

Fig. 7.2 Precedence and associativity of the operators discussed so far.

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7.3 Declaring and Allocating Arrays

Arrays are objects that occupy space in memory. All objects in Java (including arrays) must be allocated dynamically with operator **new**. For an array, the programmer specifies the type of the array elements and the number of elements as part of the **new** operation. To allocate 12 elements for integer array **c** in Fig. 7.1, use the declaration

```
int c[] = new int[ 12 ];
```

The preceding declaration also can be performed in two steps as follows:

```
int c[];             // declares the array
c = new int[ 12 ];   // allocates the array
```

When allocating an array, each element of the array receives a default value–zero for the numeric primitive-data-type elements, **false** for **boolean** elements or **null** for references (any nonprimitive type).

Common Programming Error 7.2

Unlike array declarations in several other programming languages (such as C and C++), Java array declarations must not specify the number of array elements in the square brackets after the array name; otherwise, a syntax error occurs. For example, the declaration ***int c[12];*** *causes a syntax error.*

A program can allocate memory for several arrays with a single declaration. The following declaration reserves 100 elements for **String** array **b** and 27 elements for **String** array **x**:

```
String b[] = new String[ 100 ], x[] = new String[ 27 ];
```

When declaring an array, the type of the array and the square brackets can be combined at the beginning of the declaration to indicate that all identifiers in the declaration represent arrays, as in

```
double[] array1, array2;
```

which declares both **array1** and **array2** as arrays of **double** values. As shown previously, the declaration and initialization of the array can be combined in the declaration. The following declaration reserves 10 elements for **array1** and 20 elements for **array2**:

```
double[] array1 = new double[ 10 ],
         array2 = new double[ 20 ];
```

A program can declare arrays of any data type. It is important to remember that every element of a primitive data type array contains one value of the declared data type. For example, every element of an **int** array contains an **int** value. However, in an array of a nonprimitive type, every element of the array is a reference to an object of the array's declared data type. For example, every element of a **String** array is a reference to a **String**. In arrays that store references, the references have the value **null** by default.

7.4 Examples Using Arrays

This section presents several examples using arrays that demonstrate declaring arrays, allocating arrays, initializing arrays and manipulating array elements in various ways. For

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simplicity, the examples in this section use arrays that contain elements of type **int**. Please remember that a program can declare an array of any data type.

7.4.1 Allocating an Array and Initializing Its Elements

The application of Figure 7.3 uses operator **new** to allocate dynamically an array of 10 **int** elements, which are initially zero (the default value in an array of type **int**). The program displays the array elements in tabular format in a **JTextArea**.

Line 12 declares **array**—a reference capable of referring to an array of **int** elements. Line 14 allocates the 10 elements of the array with **new** and initializes the reference. The program builds its output in the **String** called **output** that will be displayed in a **JTextArea** on a message dialog. Line 16 appends to **output** the headings for the columns displayed by the program. The columns represent the subscript for each array element and the value of each array element, respectively.

Lines 19–20 use a **for** structure to append the subscript number (represented by **counter**) and value of each array element to **output**. Note the use of zero-based counting (remember, subscripts start at 0), so that the loop can access every array element. Also, note the expression **array.length** in the **for** structure condition to determine the length of the array. In this example, the length of the array is 10, so the loop continues executing as long as the value of control variable **counter** is less than 10. For a 10-element array, the subscript values are 0 through 9, so using the less than operator **<** guarantees that the loop does not attempt to access an element beyond the end of the array.

```
1  // Fig. 7.3: InitArray.java
2  // Creating an array.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class InitArray {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int array[];             // declare reference to an array
13
14       array = new int[ 10 ];   // dynamically allocate array
15
16       String output = "Subscript\tValue\n";
17
18       // append each array element's value to String output
19       for ( int counter = 0; counter < array.length; counter++ )
20          output += counter + "\t" + array[ counter ] + "\n";
21
22       JTextArea outputArea = new JTextArea();
23       outputArea.setText( output );
24
```

Fig. 7.3 Initializing the elements of an array to zeros (part 1 of 2).

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```
25         JOptionPane.showMessageDialog( null, outputArea,
26            "Initializing an Array of int Values",
27            JOptionPane.INFORMATION_MESSAGE );
28
29         System.exit( 0 );
30      }
31   }
```

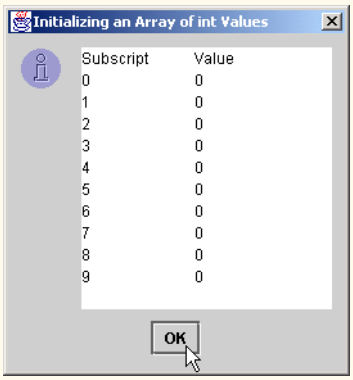

Fig. 7.3 Initializing the elements of an array to zeros (part 2 of 2).

7.4.2 Using an Initializer List to Initialize Elements of an Array

A program can allocate and initialize the elements of an array in the array declaration by following the declaration with an equal sign and a comma-separated *initializer list* enclosed in braces (**{** and **}**). In this case, the array size is determined by the number of elements in the initializer list. For example, the declaration

```
int n[] = { 10, 20, 30, 40, 50 };
```

creates a five-element array with subscripts of **0**, **1**, **2**, **3** and **4**. Note that the preceding declaration does not require the **new** operator to create the array object. When the compiler encounters an array declaration that includes an initializer list, the compiler counts the number of initializers in the list and sets up a new operation to allocate the appropriate number of array elements.

The application of Fig. 7.4 initializes an integer array with 10 values (line 14) and displays the array in tabular format in a **JTextArea** on a message dialog. The code for displaying the array elements is identical to that of Fig. 7.3.

```
1  // Fig. 7.4: InitArray.java
2  // Initializing an array with a declaration.
3
4  // Java extension packages
5  import javax.swing.*;
6
```

Fig. 7.4 Initializing the elements of an array with a declaration (part 1 of 2).

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```
 7  public class InitArray {
 8
 9     // main method begins execution of Java application
10     public static void main( String args[] )
11     {
12        // initializer list specifies number of elements and
13        // value for each element
14        int array[] = { 32, 27, 64, 18, 95, 14, 90, 70, 60, 37 };
15
16        String output = "Subscript\tValue\n";
17
18        // append each array element's value to String output
19        for ( int counter = 0; counter < array.length; counter++ )
20           output += counter + "\t" + array[ counter ] + "\n";
21
22        JTextArea outputArea = new JTextArea();
23        outputArea.setText( output );
24
25        JOptionPane.showMessageDialog( null, outputArea,
26           "Initializing an Array with a Declaration",
27           JOptionPane.INFORMATION_MESSAGE );
28
29        System.exit( 0 );
30     }
31  }
```

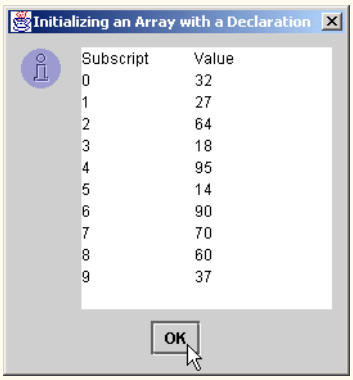

Fig. 7.4 Initializing the elements of an array with a declaration (part 2 of 2).

7.4.3 Calculating the Value to Store in Each Array Element

Some programs calculate the value stored in each array element. The application of Fig. 7.5 initializes the elements of a 10-element array to the even integers from 2 to 20 (**2**, **4**, **6**, …, **20**) and displays the array in tabular format. The **for** structure at lines 18–19 generates an array element's value by multiplying the current value of **counter** (the control variable of the loop) by **2** and adding **2**.

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```
1  // Fig. 7.5: InitArray.java
2  // Initialize array with the even integers from 2 to 20.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class InitArray {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       final int ARRAY_SIZE = 10;
13       int array[];                    // reference to int array
14
15       array = new int[ ARRAY_SIZE ];  // allocate array
16
17       // calculate value for each array element
18       for ( int counter = 0; counter < array.length; counter++ )
19          array[ counter ] = 2 + 2 * counter;
20
21       String output = "Subscript\tValue\n";
22
23       for ( int counter = 0; counter < array.length; counter++ )
24          output += counter + "\t" + array[ counter ] + "\n";
25
26       JTextArea outputArea = new JTextArea();
27       outputArea.setText( output );
28
29       JOptionPane.showMessageDialog( null, outputArea,
30          "Initializing to Even Numbers from 2 to 20",
31          JOptionPane.INFORMATION_MESSAGE );
32
33       System.exit( 0 );
34    }
35 }
```

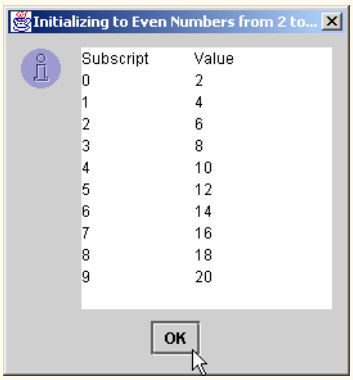

Fig. 7.5 Generating values to be placed into elements of an array.

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Line 12 uses the **final** qualifier to declare constant variable **ARRAY_SIZE**, whose value is **10**. Remember that constant variables must be initialized before they are used and cannot be modified thereafter. If an attempt is made to modify a **final** variable after it is declared as shown on line 12, the compiler issues a message like

cannot assign a value to final variable *variableName*

If an attempt is made to use a **final** variable before it is initialized, the compiler issues the error message

Variable *variableName* **may not have been initialized**

Constant variables also are called *named constants* or *read-only variables.* Such variables often can make programs more readable. Note that the term "constant variable" is an oxymoron—a contradiction in terms—like "jumbo shrimp" or "freezer burn."

Common Programming Error 7.3

Assigning a value to a constant variable after the variable has been initialized is a syntax error.

7.4.4 Summing the Elements of an Array

Often, the elements of an array represent a series of values to use in a calculation. For example, if the elements of an array represent the grades for an exam in a class, the professor may wish to total the elements of an array, then calculate the class average for the exam.

The application of Fig. 7.6 sums the values contained in the 10-element integer array. The program declares, allocates and initializes the array at line 12. The **for** structure at lines 16–17 performs the calculations. [*Note*: It is important to remember that the values being supplied as initializers for **array** normally would be read into the program. For example, in an applet the user could enter the values through a **JTextField**, or in an application the values could be read from a file on disk (discussed in Chapter 16). Reading the data into a program makes the program more flexible, because it can be used with different sets of data.]

```
1  // Fig. 7.6: SumArray.java
2  // Total the values of the elements of an array.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class SumArray {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int array[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
13       int total = 0;
14
```

Fig. 7.6 Computing the sum of the elements of an array (part 1 of 2).

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```
15         // add each element's value to total
16         for ( int counter = 0; counter < array.length; counter++ )
17            total += array[ counter ];
18
19         JOptionPane.showMessageDialog( null,
20            "Total of array elements: " + total,
21            "Sum the Elements of an Array",
22            JOptionPane.INFORMATION_MESSAGE );
23
24         System.exit( 0 );
25      }
26   }
```

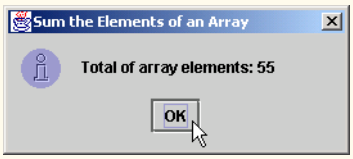

Fig. 7.6 Computing the sum of the elements of an array (part 2 of 2).

7.4.5 Using Histograms to Display Array Data Graphically

Many programs present data to users in a graphical manner. For example, numeric values are often displayed as bars in a bar chart. In such a chart, longer bars represent larger numeric values. One simple way to display numeric data graphically is with a *histogram* that shows each numeric value as a bar of asterisks (**`*`**).

Our next application (Fig. 7.7) reads numbers from an array and graphs the information in the form of a bar chart (or histogram). The program displays each number followed by a bar consisting of that many asterisks. The nested **`for`** loop (lines 17–24) appends the bars to the **`String`** that will be displayed in **`JTextArea outputArea`** on a message dialog. Note the loop continuation condition of the inner **`for`** structure at line 22 (**`stars <= array[ counter ]`**). Each time the program reaches the inner **`for`** structure, the loop counts from **`1`** to **`array[ counter ]`**, thus using a value in **`array`** to determine the final value of the control variable **`stars`** and the number of asterisks to display.

```
1  // Fig. 7.7: Histogram.java
2  // Histogram printing program.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class Histogram {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int array[] = { 19, 3, 15, 7, 11, 9, 13, 5, 17, 1 };
13
14       String output = "Element\tValue\tHistogram";
```

Fig. 7.7 A program that prints histograms (part 1 of 2).

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```
15
16          // for each array element, output a bar in histogram
17          for ( int counter = 0; counter < array.length; counter++ ) {
18             output +=
19                "\n" + counter + "\t" + array[ counter ] + "\t";
20
21             // print bar of asterisks
22             for ( int stars = 0; stars < array[ counter ]; stars++ )
23                output += "*";
24          }
25
26          JTextArea outputArea = new JTextArea();
27          outputArea.setText( output );
28
29          JOptionPane.showMessageDialog( null, outputArea,
30             "Histogram Printing Program",
31             JOptionPane.INFORMATION_MESSAGE );
32
33          System.exit( 0 );
34       }
35    }
```

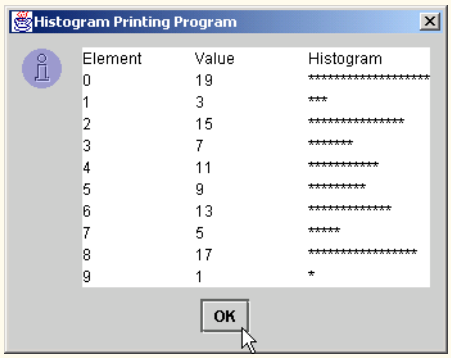

Fig. 7.7 A program that prints histograms (part 2 of 2).

7.4.6 Using the Elements of an Array as Counters

Sometimes programs use a series of counter variables to summarize data, such as the results of a survey. In Chapter 6, we used a series of counters in our die-rolling program to track the number of occurrences of each side on a six-sided die as the program rolled the die 6000 times. We also indicated that there is a more elegant method of writing the program of Fig. 6.8. An array version of this application is shown in Fig. 7.8.

```
1  // Fig. 7.8: RollDie.java
2  // Roll a six-sided die 6000 times
3
4  // Java extension packages
5  import javax.swing.*;
6
```

Fig. 7.8 Die-rolling program using arrays instead of **switch** (part 1 of 2).

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```
 7  public class RollDie {
 8
 9     // main method begins execution of Java application
10     public static void main( String args[] )
11     {
12        int face, frequency[] = new int[ 7 ];
13
14        // roll die 6000 times
15        for ( int roll = 1; roll <= 6000; roll++ ) {
16           face = 1 + ( int ) ( Math.random() * 6 );
17
18           // use face value as subscript for frequency array
19           ++frequency[ face ];
20        }
21
22        String output = "Face\tFrequency";
23
24        // append frequencies to String output
25        for ( face = 1; face < frequency.length; face++ )
26           output += "\n" + face + "\t" + frequency[ face ];
27
28        JTextArea outputArea = new JTextArea();
29        outputArea.setText( output );
30
31        JOptionPane.showMessageDialog( null, outputArea,
32           "Rolling a Die 6000 Times",
33           JOptionPane.INFORMATION_MESSAGE );
34
35        System.exit( 0 );
36     }
37  }
```

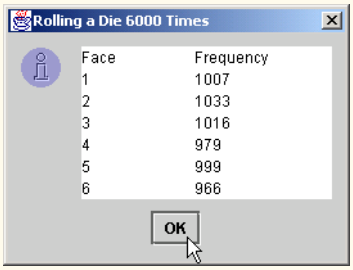

Fig. 7.8 Die-rolling program using arrays instead of **switch** (part 2 of 2).

The program uses the seven-element array **frequency** to count the occurrences of each side of the die. This program replaces lines 20–46 of Fig. 6.8 with line 19 of this program. Line 19 uses the random **face** value as the subscript for array **frequency** to determine which element the program should increment during each iteration of the loop. Since the random number calculation on line 19 produces numbers from 1 to 6 (the values for a six-sided die), the **frequency** array must be large enough to store six counters. However, in this program, we chose to use a seven-element array. We ignore the first array element, **frequency[0]**, because it is more logical to have the face value 1 increment

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frequency[1] than **frequency[0]**. This allows us to use each face value directly as a subscript for the **frequency** array.

Good Programming Practice 7.1

Strive for program clarity. It is sometimes worthwhile to trade off the most efficient use of memory or processor time in favor of writing clearer programs.

Performance Tip 7.1

Sometimes performance considerations far outweigh clarity considerations.

Also, lines 25–26 of this program replace lines 52–55 from Fig. 6.8. We can loop through array **frequency**, so we do not have to enumerate each line of text to display in the **JTextArea** as we did in Fig. 6.8.

7.4.7 Using Arrays to Analyze Survey Results

Our next example uses arrays to summarize the results of data collected in a survey. Consider the problem statement:

> *Forty students were asked to rate the quality of the food in the student cafeteria on a scale of 1 to 10 (1 means awful and 10 means excellent). Place the 40 responses in an integer array and summarize the results of the poll.*

This is a typical array processing application (see Fig. 7.9). We wish to summarize the number of responses of each type (i.e., 1 through 10). The array **responses** is a 40-element integer array of the students' responses to the survey. We use an 11-element array **frequency** to count the number of occurrences of each response. As in Fig. 7.8, we ignore the first element (**frequency[0]**) because it is more logical to have the response 1 increment **frequency[1]** than **frequency[0]**. This allows us to use each response directly as a subscript on the **frequency** array. Each element of the array is used as a counter for one of the survey responses.

```
1  // Fig. 7.9: StudentPoll.java
2  // Student poll program
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class StudentPoll {
8
9     // main method begins execution of Java application
10    public static void main( String args[] )
11    {
12       int responses[] = { 1, 2, 6, 4, 8, 5, 9, 7, 8, 10,
13                           1, 6, 3, 8, 6, 10, 3, 8, 2, 7,
14                           6, 5, 7, 6, 8, 6, 7, 5, 6, 6,
15                           5, 6, 7, 5, 6, 4, 8, 6, 8, 10 };
16       int frequency[] = new int[ 11 ];
17
```

Fig. 7.9 A simple student-poll analysis program (part 1 of 2).

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```
18         // for each answer, select value of an element of
19         // responses array and use that value as subscript in
20         // frequency array to determine element to increment
21         for ( int answer = 0; answer < responses.length; answer++ )
22            ++frequency[ responses[ answer ] ];
23
24         String output = "Rating\tFrequency\n";
25
26         // append frequencies to String output
27         for ( int rating = 1; rating < frequency.length; rating++ )
28            output += rating + "\t" + frequency[ rating ] + "\n";
29
30         JTextArea outputArea = new JTextArea();
31         outputArea.setText( output );
32
33         JOptionPane.showMessageDialog( null, outputArea,
34            "Student Poll Program",
35            JOptionPane.INFORMATION_MESSAGE );
36
37         System.exit( 0 );
38      }
39   }
```

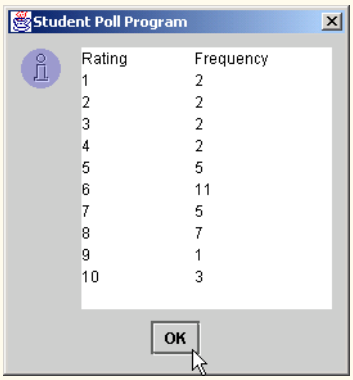

Fig. 7.9 A simple student-poll analysis program (part 2 of 2).

The **for** loop (lines 21–22) takes the responses one at a time from array **responses** and increments one of the 10 counters in the **frequency** array (**frequency[1]** to **frequency[10]**). The key statement in the loop is line 22, which increments the appropriate **frequency** counter, depending on the value of **responses[answer]**.

Let's consider several iterations of the **for** loop. When counter **answer** is **0**, **responses[answer]** is the value of the first element of array **responses** (i.e., **1**), so the program interprets **++frequency[responses[answer]];** as

```
++frequency[ 1 ];
```

which increments the value in array element one. To evaluate the expression, start with the value in the innermost set of square brackets (**answer**). Once you know the value of **answer**, plug that value into the expression and evaluate the next outer set of square brackets

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(**responses[answer]**). Then, use that value as the subscript for the **frequency** array to determine which counter to increment.

When **answer** is **1**, **responses[answer]** is the value of **responses**' second element (**2**), so the program interprets **++frequency[responses[answer]];** as

```
++frequency[ 2 ];
```

which increments array element two (the third element of the array).

When **answer** is **2**, **responses[answer]** is the value of **responses**' third element (**6**), so the program interprets **++frequency[responses[answer]];** as

```
++frequency[ 6 ];
```

which increments array element six (the seventh element of the array), and so on. Regardless of the number of responses processed in the survey, the program requires only an 11-element array (ignoring element zero) to summarize the results, because all the response values are between 1 and 10 and the subscript values for an 11-element array are 0 through 10. Also, note that the summarized results are correct, because the elements of array **frequency** were initialized to zero when the array was allocated with **new**.

If the data contained invalid values, such as 13, the program would attempt to add **1** to **frequency[13]**. This is outside the bounds of the array. In the C and C++ programming languages, such a reference would be allowed by the compiler and at execution time. The program would "walk" past the end of the array to where it thought element number 13 was located and add 1 to whatever happened to be at that location in memory. This could potentially modify another variable in the program or even result in premature program termination. Java provides mechanisms to prevent accessing elements outside the bounds of the array.

Common Programming Error 7.4

Referring to an element outside the array bounds is a logic error.

Testing and Debugging Tip 7.1

When a Java program executes, the Java interpreter checks array element subscripts to be sure they are valid (i.e., all subscripts must be greater than or equal to 0 and less than the length of the array). If there is an invalid subscript, Java generates an exception.

Testing and Debugging Tip 7.2

Exceptions indicate that an error occurred in a program. A programmer can write code to recover from an exception and continue program execution instead of abnormally terminating the program. When an invalid array reference occurs, Java generates an ***ArrayIndexOutOfBoundsException****. Chapter 14 covers exception handling in detail.*

Testing and Debugging Tip 7.3

When looping through an array, the array subscript should never go below 0 and should always be less than the total number of elements in the array (one less than the size of the array). The loop terminating condition should prevent accessing elements outside this range.

Testing and Debugging Tip 7.4

Programs should validate all input values to prevent erroneous information from affecting a program's calculations.

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7.5 References and Reference Parameters

Two ways to pass arguments to methods (or functions) in many programming languages (like C and C++) are *pass-by-value* and *pass-by-reference* (also called *call-by-value* and *call-by-reference*). When an argument is passed by value, a *copy* of the argument's value is made and passed to the called method.

Testing and Debugging Tip 7.5

With pass-by-value, changes to the called method's copy do not affect the original variable's value in the calling method. This prevents the accidental side effects that so greatly hinder the development of correct and reliable software systems.

When an argument is passed by reference, the caller gives the called method the ability to access the caller's data directly and to modify that data if the called method so chooses. Pass-by-reference improves performance, because it eliminates the overhead of copying large amounts of data.

Software Engineering Observation 7.1

Unlike other languages, Java does not allow the programmer to choose whether to pass each argument by value or by reference. Primitive data type variables are always passed by value. Objects are not passed to methods; rather, references to objects are passed to methods. The references themselves are passed by value—a copy of a reference is passed to a method. When a method receives a reference to an object, the method can manipulate the object directly.

Software Engineering Observation 7.2

When returning information from a method via a **`return`** *statement, primitive-data-type variables are always returned by value (i.e., a copy is returned) and objects are always returned by reference (i.e., a reference to the object is returned).*

To pass a reference to an object into a method, simply specify the reference name in the method call. Mentioning the reference by its parameter name in the body of the called method actually refers to the original object in memory, and the original object can be accessed directly by the called method.

Arrays are treated as objects by Java; therefore, arrays are passed to methods by reference—a called method can access the elements of the caller's original arrays. The name of an array is actually a reference to an object that contains the array elements and the **`length`** instance variable, which indicates the number of elements in the array. In the next section, we demonstrate pass-by-value and pass-by-reference using arrays.

Performance Tip 7.2

Passing arrays by reference makes sense for performance reasons. If arrays were passed by value, a copy of each element would be passed. For large, frequently passed arrays, this would waste time and would consume considerable storage for the copies of the arrays.

7.6 Passing Arrays to Methods

To pass an array argument to a method, specify the name of the array without any brackets. For example, if array **`hourlyTemperatures`** is declared as

```
int hourlyTemperatures[] = new int[ 24 ];
```

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the method call

```
modifyArray( hourlyTemperatures );
```

passes array **hourlyTemperatures** to method **modifyArray**. In Java, every array object "knows" its own size (via the **length** instance variable). Thus, when we pass an array object into a method, we are not required to pass the size of the array as an additional argument.

Although entire arrays and objects referred to by individual elements of a nonprimitive-type array are passed by reference, individual array elements of primitive data types are passed by value exactly as simple variables are. Such simple single pieces of data are called *scalars* or *scalar quantities*. To pass an array element to a method, use the subscripted name of the array element as an argument in the method call.

For a method to receive an array through a method call, the method's parameter list must specify an array parameter (or several if more than one array is to be received). For example, the method header for method **modifyArray** might be written as

```
void modifyArray( int b[] )
```

indicating that **modifyArray** expects to receive an integer array in parameter **b**. Since arrays are passed by reference, when the called method uses the array name **b**, it refers to the actual array in the caller (array **hourlyTemperatures** in the preceding call).

The applet of Fig. 7.10 demonstrates the difference between passing an entire array and passing an array element. Once again, we use an applet here, because we have not yet defined an application that contains methods other than **main**. We are still taking advantage of some of the features provided for free in an applet (such as the automatic creation of an applet object and the automatic calls to **init**, **start** and **paint** by the applet container). In Chapter 9, Object-Oriented Programming, we introduce applications that execute in their own windows. At that point, we will begin to see application classes containing several methods.

Lines 15–17 in method **init** define the **JTextArea** called **outputArea** and attach it to the applet's content pane. The **for** structure at lines 26–27 appends the five elements of **array** (an array of **int** values) to the **String** called **output**. Line 29 invokes method **modifyArray** and passes it **array** as an argument. Method **modifyArray** (lines 50–54) multiplies each element by 2. To illustrate that **array**'s elements were modified, the **for** structure at lines 34–35 appends the five elements of **array** to **output** again. As the screen capture shows, method **modifyArray** did change the value of each element.

```
1  // Fig. 7.10: PassArray.java
2  // Passing arrays and individual array elements to methods
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
```

Fig. 7.10 Passing arrays and individual array elements to methods (part 1 of 3).

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```
10  public class PassArray extends JApplet {
11
12     // initialize applet
13     public void init()
14     {
15        JTextArea outputArea = new JTextArea();
16        Container container = getContentPane();
17        container.add( outputArea );
18
19        int array[] = { 1, 2, 3, 4, 5 };
20
21        String output =
22           "Effects of passing entire array by reference:\n" +
23           "The values of the original array are:\n";
24
25        // append original array elements to String output
26        for ( int counter = 0; counter < array.length; counter++ )
27           output += "   " + array[ counter ];
28
29        modifyArray( array );  // array passed by reference
30
31        output += "\n\nThe values of the modified array are:\n";
32
33        // append modified array elements to String output
34        for ( int counter = 0; counter < array.length; counter++ )
35           output += "   " + array[ counter ];
36
37        output += "\n\nEffects of passing array " +
38                  "element by value:\n" +
39                  "a[3] before modifyElement: " + array[ 3 ];
40
41        // attempt to modify array[ 3 ]
42        modifyElement( array[ 3 ] );
43
44        output += "\na[3] after modifyElement: " + array[ 3 ];
45        outputArea.setText( output );
46
47     }  // end method init
48
49     // multiply each element of an array by 2
50     public void modifyArray( int array2[] )
51     {
52        for ( int counter = 0; counter < array2.length; counter++ )
53           array2[ counter ] *= 2;
54     }
55
56     // multiply argument by 2
57     public void modifyElement( int element )
58     {
59        element *= 2;
60     }
61
62  }  // end class PassArray
```

Fig. 7.10 Passing arrays and individual array elements to methods (part 2 of 3).

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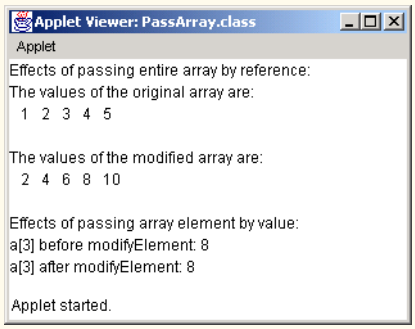

Fig. 7.10 Passing arrays and individual array elements to methods (part 3 of 3).

Next, the program demonstrates that individual elements of primitive-type arrays are passed to methods by value. To show the value of **`array[ 3 ]`** before calling method **`modifyElement`**, lines 37–39 append the value of **`array[ 3 ]`** (and other information) to **`output`**. Line 42 invokes method **`modifyElement`** and passes **`array[ 3 ]`** as an argument. Remember that **`array[ 3 ]`** is actually one **`int`** value in **`array`**. Also, remember that values of primitive types are passed to methods by value. Therefore, the program passes a copy of **`array[ 3 ]`**. Method **`modifyElement`** multiplies its argument by 2 and stores the result in its parameter **`element`**. Method parameters are local variables, so when **`modifyElement`** terminates, the local variable **`element`** is destroyed. Thus, when the program returns control to **`init`**, line 44 appends the unmodified value of **`array[ 3 ]`** **`output`**. Line 45 displays the results in the **`JTextArea`**.

7.7 Sorting Arrays

Sorting data (i.e., placing the data into some particular order such as ascending or descending) is one of the most important computing applications. A bank sorts all checks by account number so that it can prepare individual bank statements at the end of each month. Telephone companies sort their lists of accounts by last name and, within that, by first name, to make it easy to find phone numbers. Virtually every organization must sort some data and in many cases massive amounts of data. Sorting data is an intriguing problem that has attracted some of the most intense research efforts in the field of computer science. In this chapter, we discuss one of the simplest sorting schemes. In the exercises in this chapter, Chapter 19 and Chapter 21, we investigate more complex schemes that yield superior performance.

Performance Tip 7.3

Sometimes, the simplest algorithms perform poorly. Their virtue is that they are easy to program, test and debug. Sometimes, more complex algorithms are required to realize maximum performance.

Figure 7.11 sorts the values of **`array`** (a the 10-element array of **`int`** values) into ascending order. The technique we use is called the *bubble sort* or the *sinking sort*, because the smaller values gradually "bubble" their way to the top of the array (i.e., toward the first element) like air bubbles rising in water, while the larger values sink to the bottom (end) of the array. The technique uses nested loops to make several passes through the array. Each pass compares successive pairs of elements. If a pair is in increasing order (or the values

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are equal), the bubble sort leaves the values as they are. If a pair is in decreasing order, the bubble sort swaps their values in the array. The applet contains methods **init**, **bubbleSort** and **swap**. Method **init** (lines 13–36) initializes the applet. Method **bubbleSort** (lines 39–58) is called from **init** to sort the elements of **array**. Method **bubbleSort** calls method **swap** (lines 61–68) as necessary to exchange two elements of the array.

Lines 24–25 append the original values of **array** to the **String** called **output**. Line 27 invokes method **bubbleSort** and passes **array** as the array to sort.

Method **bubbleSort** receives the array as parameter **array2**. The nested **for** structure at lines 42–56 performs the sort. The outer loop controls the number of passes of the array. The inner loop controls the comparisons and swapping (if necessary) of the elements during each pass.

```
1  // Fig. 7.11: BubbleSort.java
2  // Sort an array's values into ascending order.
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class BubbleSort extends JApplet {
11
12    // initialize applet
13    public void init()
14    {
15       JTextArea outputArea = new JTextArea();
16       Container container = getContentPane();
17       container.add( outputArea );
18
19       int array[] = { 2, 6, 4, 8, 10, 12, 89, 68, 45, 37 };
20
21       String output = "Data items in original order\n";
22
23       // append original array values to String output
24       for ( int counter = 0; counter < array.length; counter++ )
25          output += "   " + array[ counter ];
26
27       bubbleSort( array );  // sort array
28
29       output += "\n\nData items in ascending order\n";
30
31       // append sorted\ array values to String output
32       for ( int counter = 0; counter < array.length; counter++ )
33          output += "   " + array[ counter ];
34
35       outputArea.setText( output );
36    }
37
```

Fig. 7.11 Sorting an array with bubble sort (part 1 of 2).

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```
38     // sort elements of array with bubble sort
39     public void bubbleSort( int array2[] )
40     {
41        // loop to control number of passes
42        for ( int pass = 1; pass < array2.length; pass++ ) {
43
44           // loop to control number of comparisons
45           for ( int element = 0;
46                 element < array2.length - 1;
47                 element++ ) {
48
49              // compare side-by-side elements and swap them if
50              // first element is greater than second element
51              if ( array2[ element ] > array2[ element + 1 ] )
52                 swap( array2, element, element + 1 );
53
54           }  // end loop to control comparisons
55
56        }  // end loop to control passes
57
58     }  // end method bubbleSort
59
60     // swap two elements of an array
61     public void swap( int array3[], int first, int second )
62     {
63        int hold;  // temporary holding area for swap
64
65        hold = array3[ first ];
66        array3[ first ] = array3[ second ];
67        array3[ second ] = hold;
68     }
69
70  }  // end class BubbleSort
```

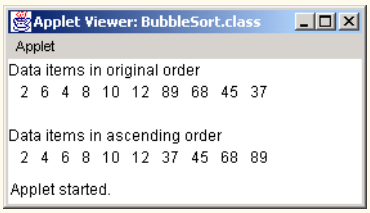

Fig. 7.11 Sorting an array with bubble sort (part 2 of 2).

Method **bubbleSort** first compares **array2[0]** to **array2[1]**, then **array2[1]** to **array2[2]**, then **array2[2]** to **array2[3]** so on until it completes the pass by comparing **array2[8]** to **array2[9]**. Although there are 10 elements, the comparison loop performs only nine comparisons. The comparisons performed in a bubble sort could cause a large value to move down the array (sink) many positions on a single pass. However, a small value may move up (bubble) only one position per pass. On the first pass, the largest value is guaranteed to sink to the bottom element of the array,

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array2[9]. On the second pass, the second largest value is guaranteed to sink to **array2[8]**. On the ninth pass, the ninth largest value sinks to **array2[1]**. This leaves the smallest value in **array2[0]**, so only nine passes are required to sort a 10-element array.

If a comparison reveals that the two elements are in descending order, **bubbleSort** calls method **swap** to exchange the two elements, so they will be in ascending order in the array. Method **swap** receives a reference to the array (which it calls **array3**) and two integers representing the subscripts of the two elements of the array to exchange. The exchange is performed by the three assignments

```
hold = array3[ first ];
array3[ first ] = array3[ second ];
array3[ second ] = hold;
```

where the extra variable **hold** temporarily stores one of the two values being swapped. The swap cannot be performed with only the two assignments

```
array3[ first ] = array3[ second ];
array3[ second ] = array3[ first ];
```

If **array3[first]** is **7** and **array3[second]** is **5**, after the first assignment both array elements contain **5** and the value **7** is lost, hence the need for the extra variable **hold**.

The chief virtue of the bubble sort is that it is easy to program. However, the bubble sort runs slowly. This becomes apparent when sorting large arrays. In Exercise 7.11, we ask you to develop more efficient versions of the bubble sort. Other exercises investigate some sorting algorithms that are far more efficient than the bubble sort. More advanced courses (often titled "Data Structures," "Algorithms" or "Computational Complexity") investigate sorting and searching in greater depth.

7.8 Searching Arrays: Linear Search and Binary Search

Often, a programmer will be working with large amounts of data stored in arrays. It may be necessary to determine whether an array contains a value that matches a certain *key value*. The process of locating a particular element value in an array is called *searching*. In this section, we discuss two searching techniques—the simple *linear search* technique and the more efficient *binary search* technique. Exercise 7.31 and Exercise 7.32 at the end of this chapter ask you to implement recursive versions of the linear search and the binary search.

7.8.1 Searching an Array with Linear Search

In the applet of Fig. 7.12, method **linearSearch** (defined at lines 52–62) uses a **for** structure (lines 55–59) containing an **if** structure to compare each element of an array with a *search key*. If the search key is found, the method returns the subscript value for the element to indicate the exact position of the search key in the array. If the search key is not found, the method returns **-1** to indicate that the search key was not found. We return **-1** because it is not a valid subscript number. If the array being searched is not in any particular order, it is just as likely that the search key will be found in the first element as the last. On average, therefore, the program will have to compare the search key with half the elements of the array.

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Figure 7.12 contains a 100-element array filled with the even integers from 0 to 198. The user types the search key in a **`JTextField`** and presses *Enter* to start the search. [*Note*: We pass the array to **`linearSearch`** even though the array is an instance variable of the class. We do this because an array normally is passed to a method of another class for sorting. For example, class **`Arrays`** (see Chapter 21) contains a variety of **`static`** methods for sorting arrays, searching arrays, comparing the contents of arrays and filling arrays of all the primitive types, **`Object`**s and **`String`**s.]

```
1  // Fig. 7.12: LinearSearch.java
2  // Linear search of an array
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class LinearSearch extends JApplet
12    implements ActionListener {
13
14    JLabel enterLabel, resultLabel;
15    JTextField enterField, resultField;
16    int array[];
17
18    // set up applet's GUI
19    public void init()
20    {
21       // get content pane and set its layout to FlowLayout
22       Container container = getContentPane();
23       container.setLayout( new FlowLayout() );
24
25       // set up JLabel and JTextField for user input
26       enterLabel = new JLabel( "Enter integer search key" );
27       container.add( enterLabel );
28
29       enterField = new JTextField( 10 );
30       container.add( enterField );
31
32       // register this applet as enterField's action listener
33       enterField.addActionListener( this );
34
35       // set up JLabel and JTextField for displaying results
36       resultLabel = new JLabel( "Result" );
37       container.add( resultLabel );
38
39       resultField = new JTextField( 20 );
40       resultField.setEditable( false );
41       container.add( resultField );
42
43       // create array and populate with even integers 0 to 198
44       array = new int[ 100 ];
```

Fig. 7.12 Linear search of an array (part 1 of 2).

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```
45
46          for ( int counter = 0; counter < array.length; counter++ )
47             array[ counter ] = 2 * counter;
48
49       }  // end method init
50
51       // Search array for specified key value
52       public int linearSearch( int array2[], int key )
53       {
54          // loop through array elements
55          for ( int counter = 0; counter < array2.length; counter++ )
56
57             // if array element equals key value, return location
58             if ( array2[ counter ] == key )
59                return counter;
60
61          return -1;  // key not found
62       }
63
64       // obtain user input and call method linearSearch
65       public void actionPerformed( ActionEvent actionEvent )
66       {
67          // input also can be obtained with enterField.getText()
68          String searchKey = actionEvent.getActionCommand();
69
70          // Array a is passed to linearSearch even though it
71          // is an instance variable. Normally an array will
72          // be passed to a method for searching.
73          int element =
74             linearSearch( array, Integer.parseInt( searchKey ) );
75
76          // display search result
77          if ( element != -1 )
78             resultField.setText( "Found value in element " +
79                element );
80          else
81             resultField.setText( "Value not found" );
82       }
83
84    }  // end class LinearSearch
```

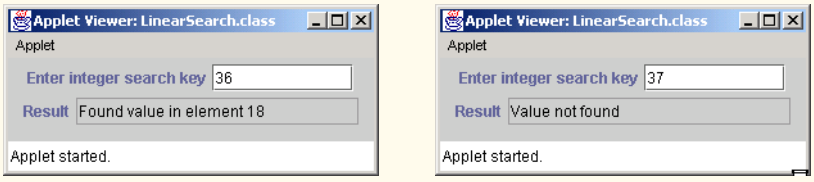

Fig. 7.12 Linear search of an array (part 2 of 2).

The linear search method works well for small arrays or for unsorted arrays. However, for large arrays, linear searching is inefficient. If the array is sorted, the high-speed *binary search* technique presented in the next section can be used.

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7.8.2 Searching a Sorted Array with Binary Search

The binary search algorithm eliminates half of the elements in the array being searched after each comparison. The algorithm locates the middle array element and compares it to the search key. If they are equal, the search key has been found and binary search returns the subscript of that element. Otherwise, binary search reduces the problem to searching half of the array. If the search key is less than the middle array element, the first half of the array will be searched; otherwise, the second half of the array will be searched. If the search key is not the middle element in the specified subarray (piece of the original array), the algorithm repeats on one quarter of the original array. The search continues until the search key is equal to the middle element of a subarray or until the subarray consists of one element that is not equal to the search key (i.e., the search key is not found).

In a worst-case scenario, searching a sorted array of 1024 elements will take only 10 comparisons using a binary search. Repeatedly dividing 1024 by 2 (because after each comparison we are able to eliminate half of the array) yields the values 512, 256, 128, 64, 32, 16, 8, 4, 2 and 1. The number 1024 (2^{10}) is divided by 2 only ten times to get the value 1. Dividing by 2 is equivalent to one comparison in the binary search algorithm. An array of 1,048,576 (2^{20}) elements takes a maximum of 20 comparisons to find the key. An array of one billion elements takes a maximum of 30 comparisons to find the key. This is a tremendous increase in performance over the linear search that required comparing the search key to an average of half the elements in the array. For a one-billion-element array, this is a difference between an average of 500 million comparisons and a maximum of 30 comparisons! The maximum number of comparisons needed for the binary search of any sorted array is the exponent of the first power of 2 greater than the number of elements in the array.

Figure 7.13 presents the iterative version of method **`binarySearch`** (lines 85–116). The method receives two arguments—an integer array called **`array2`** (the array to search) and an integer **`key`** (the search key). The program passes the array to **`binarySearch`** even though the array is an instance variable of the class. Once again, we do this because an array normally is passed to a method of another class for sorting. If **`key`** matches the **`middle`** element of a subarray, **`binarySearch`** returns **`middle`** (the subscript of the current element) to indicate that the value was found and the search is complete. If **`key`** does not match the **`middle`** element of a subarray, **`binarySearch`** adjusts the **`low`** subscript or **`high`** subscript (both declared in the method), to continue the search using a smaller subarray. If **`key`** is less than the middle element, the **`high`** subscript is set to **`middle - 1`** and the search continues on the elements from **`low`** to **`middle - 1`**. If **`key`** is greater than the middle element, the **`low`** subscript is set to **`middle + 1`** and the search continues on the elements from **`middle + 1`** to **`high`**. Method **`binarySearch`** performs these comparisons in the nested **`if/else`** structure at lines 102–111.

```
1  // Fig. 7.13: BinarySearch.java
2  // Binary search of an array
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.text.*;
```

Fig. 7.13 Binary search of a sorted array (part 1 of 5)

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```
 8
 9  // Java extension packages
10  import javax.swing.*;
11
12  public class BinarySearch extends JApplet
13     implements ActionListener {
14
15     JLabel enterLabel, resultLabel;
16     JTextField enterField, resultField;
17     JTextArea output;
18
19     int array[];
20     String display = "";
21
22     // set up applet's GUI
23     public void init()
24     {
25        // get content pane and set its layout to FlowLayout
26        Container container = getContentPane();
27        container.setLayout( new FlowLayout() );
28
29        // set up JLabel and JTextField for user input
30        enterLabel = new JLabel( "Enter integer search key" );
31        container.add( enterLabel );
32
33        enterField = new JTextField( 10 );
34        container.add( enterField );
35
36        // register this applet as enterField's action listener
37        enterField.addActionListener( this );
38
39        // set up JLabel and JTextField for displaying results
40        resultLabel = new JLabel( "Result" );
41        container.add( resultLabel );
42
43        resultField = new JTextField( 20 );
44        resultField.setEditable( false );
45        container.add( resultField );
46
47        // set up JTextArea for displaying comparison data
48        output = new JTextArea( 6, 60 );
49        output.setFont( new Font( "Monospaced", Font.PLAIN, 12 ) );
50        container.add( output );
51
52        // create array and fill with even integers 0 to 28
53        array = new int[ 15 ];
54
55        for ( int counter = 0; counter < array.length; counter++ )
56           array[ counter ] = 2 * counter;
57
58     }  // end method init
59
```

Fig. 7.13 Binary search of a sorted array (part 2 of 5)

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```
60     // obtain user input and call method binarySearch
61     public void actionPerformed( ActionEvent actionEvent )
62     {
63        // input also can be obtained with enterField.getText()
64        String searchKey = actionEvent.getActionCommand();
65
66        // initialize display string for new search
67        display = "Portions of array searched\n";
68
69        // perform binary search
70        int element =
71           binarySearch( array, Integer.parseInt( searchKey ) );
72
73        output.setText( display );
74
75        // display search result
76        if ( element != -1 )
77           resultField.setText(
78              "Found value in element " + element );
79        else
80           resultField.setText( "Value not found" );
81
82     }  // end method actionPerformed
83
84     // method to perform binary search of an array
85     public int binarySearch( int array2[], int key )
86     {
87        int low = 0;                  // low element subscript
88        int high = array.length - 1;  // high element subscript
89        int middle;                   // middle element subscript
90
91        // loop until low subscript is greater than high subscript
92        while ( low <= high ) {
93
94           // determine middle element subscript
95           middle = ( low + high ) / 2;
96
97           // display subset of array elements used in this
98           // iteration of binary search loop
99           buildOutput( array2, low, middle, high );
100
101          // if key matches middle element, return middle location
102          if ( key == array[ middle ] )
103             return middle;
104
105          // if key less than middle element, set new high element
106          else if ( key < array[ middle ] )
107             high = middle - 1;
108
109          // key greater than middle element, set new low element
110          else
111             low = middle + 1;
112       }
```

Fig. 7.13 Binary search of a sorted array (part 3 of 5)

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```
113
114         return -1;    // key not found
115
116      }  // end method binarySearch
117
118      // build row of output showing subset of array elements
119      // currently being processed
120      void buildOutput( int array3[],
121         int low, int middle, int high )
122      {
123         // create 2-digit integer number format
124         DecimalFormat twoDigits = new DecimalFormat( "00" );
125
126         // loop through array elements
127         for ( int counter = 0; counter < array3.length;
128            counter++ ) {
129
130            // if counter outside current array subset, append
131            // padding spaces to String display
132            if ( counter < low || counter > high )
133               display += "    ";
134
135            // if middle element, append element to String display
136            // followed by asterisk (*) to indicate middle element
137            else if ( counter == middle )
138               display +=
139                  twoDigits.format( array3[ counter ] ) + "* ";
140
141            // append element to String display
142            else
143               display +=
144                  twoDigits.format( array3[ counter ] ) + "  ";
145
146         }  // end for structure
147
148         display += "\n";
149
150      }  // end method buildOutput
151
152   }  // end class BinarySearch
```

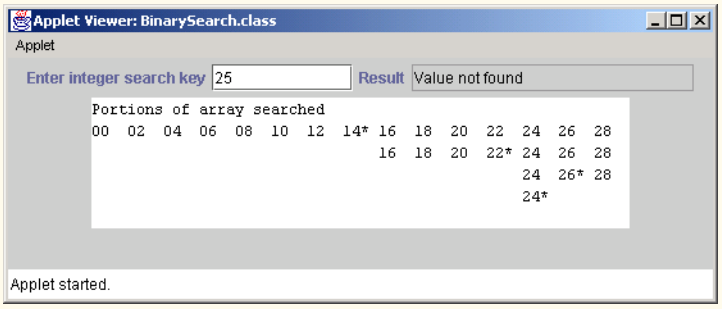

Fig. 7.13 Binary search of a sorted array (part 4 of 5)

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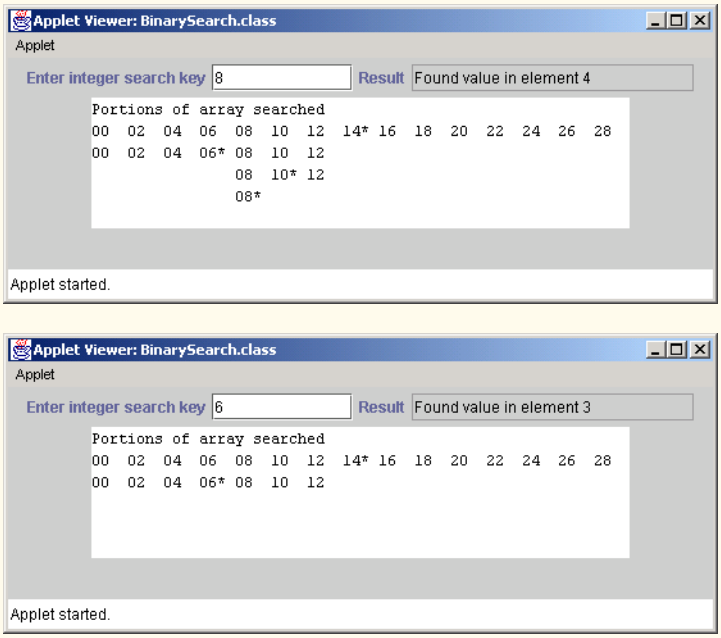

Fig. 7.13 Binary search of a sorted array (part 5 of 5)

The program uses a 15-element array. The first power of 2 greater than the number of array elements is 16 (2^4); therefore, **`binarySearch`** requires at most four comparisons to find the **`key`**. To illustrate this, line 99 of method **`binarySearch`** calls method **`buildOutput`** (defined at lines 120–150) to output each subarray during the binary search process. Method **`buildOutput`** marks the middle element in each subarray with an asterisk (**`*`**) to indicate the element to which the **`key`** is compared. Each search in this example results in a maximum of four lines of output—one per comparison.

`JTextArea output` uses *Monospaced* font (a *fixed-width font*—i.e., all characters are the same width) to help align the displayed text in each line of output. Line 49 uses method **`setFont`** to change the font displayed in **`output`**. Method **`setFont`** can change the font of text displayed on most GUI components. The method requires a ***`Font`*** (package **`java.awt`**) object as its argument. A **`Font`** object is initialized with three arguments—the **`String`** name of the font (**`"Monospaced"`**), an **`int`** representing the style of the font (***`Font.PLAIN`*** is a constant integer defined in class **`Font`** that indicates plain font) and an **`int`** representing the point size of the font (**`12`**). Java provides generic names for several fonts available on every Java platform. *Monospaced* font is also called *Courier*. Other common fonts include *Serif* (also called *TimesRoman*) and *SansSerif* (also called *Helvetica*). Java 2 actually provides access to all fonts on your system through methods of class ***`GraphicsEnvironment`***. The style can also be ***`Font.BOLD`***, ***`Font.ITALIC`*** or **`Font.BOLD + Font.ITALIC`**. The point size represents the size of the font—there are 72 points to an inch. The actual size of the text as it appears on the screen may vary based on the size of the screen and the screen resolution. We discuss font manipulation again in Chapter 11.

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7.9 Multiple-Subscripted Arrays

Multiple-subscripted arrays with two subscripts are often used to represent *tables* of values consisting of information arranged in *rows* and *columns*. To identify a particular table element, we must specify the two subscripts—by convention, the first identifies the element's row and the second identifies the element's column. Arrays that require two subscripts to identify a particular element are called *double-subscripted arrays* or *two-dimensional arrays*. Note that multiple-subscripted arrays can have more than two subscripts. Java does not support multiple-subscripted arrays directly, but does allow the programmer to specify single-subscripted arrays whose elements are also single-subscripted arrays, thus achieving the same effect. Figure 7.14 illustrates a double-subscripted array, **a**, containing three rows and four columns (i.e., a 3-by-4 array). In general, an array with *m* rows and *n* columns is called an *m-by-n array*.

Every element in array **a** is identified in Fig. 7.14 by an element name of the form **a[row][column]**; **a** is the name of the array and **row** and **column** are the subscripts that uniquely identify the row and column of each element in **a**. Notice that the names of the elements in the first row all have a first subscript of **0**; the names of the elements in the fourth column all have a second subscript of **3**.

Multiple-subscripted arrays can be initialized with initializer lists in declarations like a single-subscripted array. A double-subscripted array **b[2][2]** could be declared and initialized with

```
int b[][] = { { 1, 2 }, { 3, 4 } };
```

The values are grouped by row in braces. So, **1** and **2** initialize **b[0][0]** and **b[0][1]**, and **3** and **4** initialize **b[1][0]** and **b[1][1]**. The compiler determines the number of rows by counting the number of initializer sublists (represented by sets of braces) in the initializer list. The compiler determines the number of columns in each row by counting the number of initializer values in the initializer sublist for that row.

Multiple-subscripted arrays are maintained as arrays of arrays. The declaration

```
int b[][] = { { 1, 2 }, { 3, 4, 5 } };
```

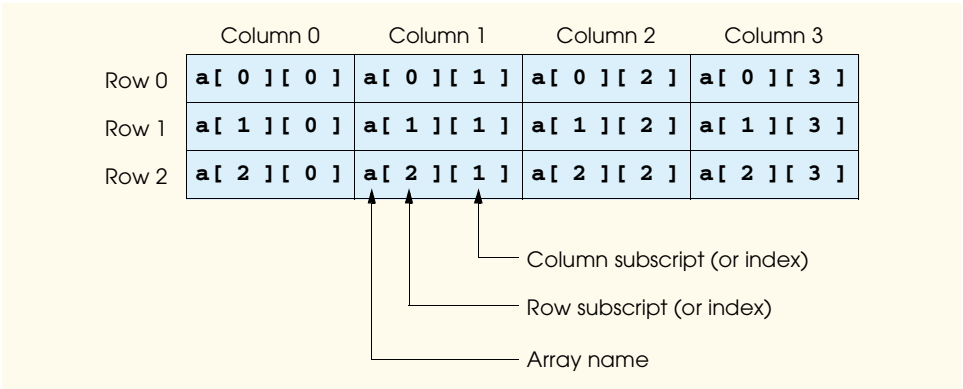

Fig. 7.14 A double-subscripted array with three rows and four columns.

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creates integer array **b** with row **0** containing two elements (**1** and **2**) and row **1** containing three elements (**3**, **4** and **5**).

A multiple-subscripted array with the same number of columns in every row can be allocated dynamically. For example, a 3-by-4 array is allocated as follows:

```
int b[][];
b = new int[ 3 ][ 4 ];
```

In this case, we the literal values **3** and **4** to specify the number of rows and number of columns, respectively. Note that programs also can use variables to specify array dimensions. As with single-subscripted arrays, the elements of a double-subscripted array are initialized when **new** creates the array object.

A multiple-subscripted array in which each row has a different number of columns can be allocated dynamically as follows:

```
int b[][];
b = new int[ 2 ][ ];   // allocate rows
b[ 0 ] = new int[ 5 ]; // allocate columns for row 0
b[ 1 ] = new int[ 3 ]; // allocate columns for row 1
```

The preceding code creates a two-dimensional array with two rows. Row **0** has five columns and row **1** has three columns.

The applet of Fig. 7.15 demonstrates initializing double-subscripted arrays in declarations and using nested **for** loops to traverse the arrays (i.e., manipulate every element of the array).

```
1  // Fig. 7.15: InitArray.java
2  // Initializing multidimensional arrays
3
4  // Java core packages
5  import java.awt.Container;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class InitArray extends JApplet {
11    JTextArea outputArea;
12
13    // set up GUI and initialize applet
14    public void init()
15    {
16       outputArea = new JTextArea();
17       Container container = getContentPane();
18       container.add( outputArea );
19
20       int array1[][] = { { 1, 2, 3 }, { 4, 5, 6 } };
21       int array2[][] = { { 1, 2 }, { 3 }, { 4, 5, 6 } };
22
23       outputArea.setText( "Values in array1 by row are\n" );
24       buildOutput( array1 );
```

Fig. 7.15 Initializing multidimensional arrays (part 1 of 2).

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```
25
26          outputArea.append( "\nValues in array2 by row are\n" );
27          buildOutput( array2 );
28       }
29
30       // append rows and columns of an array to outputArea
31       public void buildOutput( int array[][] )
32       {
33          // loop through array's rows
34          for ( int row = 0; row < array.length; row++ ) {
35
36             // loop through columns of current row
37             for ( int column = 0;
38                   column < array[ row ].length;
39                   column++ )
40                outputArea.append( array[ row ][ column ] + "   " );
41
42             outputArea.append( "\n" );
43          }
44       }
45    }
```

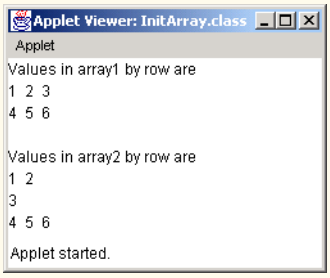

Fig. 7.15 Initializing multidimensional arrays (part 2 of 2).

The program declares two arrays in method **`init`**. The declaration of **`array1`** (line 20) provides six initializers in two sublists. The first sublist initializes the first row of the array to the values 1, 2 and 3. The second sublist initializes the second row of the array to the values 4, 5 and 6. The declaration of **`array2`** (line 21) provides six initializers in three sublists. The sublist for the first row explicitly initializes the first row to have two elements with values 1 and 2, respectively. The sublist for the second row initializes the second row to have one element with value 3. The sublist for the third row initializes the third row to the values 4, 5 and 6.

Line 24 of method **`init`** calls method **`buildOutput`** (defined at lines 31–44) to append each array's elements to **`outputArea`** (a **`JTextArea`**). Method **`buildOutput`** specifies the array parameter as **`int array[][]`** to indicate that the method receives a double-subscripted array as an argument. Note the use of a nested **`for`** structure (lines 34–43) to output the rows of a double-subscripted array. In the outer **`for`** structure, the expression **`array.length`** determines the number of rows in the array. In the inner **`for`** structure, the expression **`array[ row ].length`** determines the number of columns in the current row of the array. This condition enables the loop to determine the exact number of columns in each row.

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Many common array manipulations use **for** repetition structures. For example, the following **for** structure sets all the elements in the third row of array **a** in Fig. 7.14 to zero:

```
for ( int column = 0; column < a[ 2 ].length; column++)
   a[ 2 ][ column ] = 0;
```

We specified the *third* row; therefore, we know that the first subscript is always **2** (**0** is the first row and **1** is the second row). The **for** loop varies only the second subscript (i.e., the column subscript). The preceding **for** structure is equivalent to the assignment statements

```
a[ 2 ][ 0 ] = 0;
a[ 2 ][ 1 ] = 0;
a[ 2 ][ 2 ] = 0;
a[ 2 ][ 3 ] = 0;
```

The following nested **for** structure totals the values of all the elements in array **a**.

```
int total = 0;

for ( int row = 0; row < a.length; row++ )

   for ( int column = 0; column < a[ row ].length; column++ )

      total += a[ row ][ column ];
```

The **for** structure totals the elements of the array one row at a time. The outer **for** structure begins by setting the **row** subscript to **0** so that the elements of the first row may be totaled by the inner **for** structure. The outer **for** structure then increments **row** to **1** so that the second row can be totaled. Then, the outer **for** structure increments **row** to **2** so that the third row can be totaled. The result can be displayed when the nested **for** structure terminates.

The applet of Fig. 7.16 performs several other common array manipulations on 3-by-4 array **grades**. Each row of the array represents a student, and each column represents a grade on one of the four exams the students took during the semester. Four methods perform the array manipulations. Method **minimum** (lines 52–69) determines the lowest grade of any student for the semester. Method **maximum** (lines 72–89) determines the highest grade of any student for the semester. Method **average** (lines 93–103) determines a particular student's semester average. Method **buildString** (lines 106–121) appends the double-subscripted array to **String output** in a tabular format.

Methods **minimum**, **maximum** and **buildString** each use array **grades** and the variables **students** (number of rows in the array) and **exams** (number of columns in the array). Each method loops through array **grades** by using nested **for** structures—for example, the nested **for** structure from the definition of method **minimum** (lines 58–66). The outer **for** structure sets **row** (the row subscript) to **0** so that the elements of the first row can be compared to variable **lowGrade** in the body of the inner **for** structure. The inner **for** structure loops through the four grades of a particular row and compares each grade to **lowGrade**. If a grade is less than **lowGrade**, **lowGrade** is set to that grade. The outer **for** structure then increments the row subscript by **1**. The elements of the second row are compared to variable **lowGrade**. The outer **for** structure then increments the row subscript to **2**. The elements of the third row are compared to variable **lowGrade**. When

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execution of the nested structure is complete, **lowGrade** contains the smallest grade in the double-subscripted array. Method **maximum** works similarly to method **minimum**.

```
1  // Fig. 7.16: DoubleArray.java
2  // Double-subscripted array example
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class DoubleArray extends JApplet {
11    int grades[][] = { { 77, 68, 86, 73 },
12                       { 96, 87, 89, 81 },
13                       { 70, 90, 86, 81 } };
14
15    int students, exams;
16    String output;
17    JTextArea outputArea;
18
19    // initialize instance variables
20    public void init()
21    {
22       students = grades.length;      // number of students
23       exams = grades[ 0 ].length;    // number of exams
24
25       // create JTextArea and attach to applet
26       outputArea = new JTextArea();
27       Container container = getContentPane();
28       container.add( outputArea );
29
30       // build output string
31       output = "The array is:\n";
32       buildString();
33
34       // call methods minimum and maximum
35       output += "\n\nLowest grade: " + minimum() +
36                 "\nHighest grade: " + maximum() + "\n";
37
38       // call method average to calculate each student's average
39       for ( int counter = 0; counter < students; counter++ )
40          output += "\nAverage for student " + counter + " is " +
41             average( grades[ counter ] );
42
43       // change outputArea's display font
44       outputArea.setFont(
45          new Font( "Courier", Font.PLAIN, 12 ) );
46
47       // place output string in outputArea
48       outputArea.setText( output );
49    }
```

Fig. 7.16 Example of using double-subscripted arrays (part 1 of 3).

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```
50
51    // find minimum grade
52    public int minimum()
53    {
54       // assume first element of grages array is smallest
55       int lowGrade = grades[ 0 ][ 0 ];
56
57       // loop through rows of grades array
58       for ( int row = 0; row < students; row++ )
59
60          // loop through columns of current row
61          for ( int column = 0; column < exams; column++ )
62
63             // Test if current grade is less than lowGrade.
64             // If so, assign current grade to lowGrade.
65             if ( grades[ row ][ column ] < lowGrade )
66                lowGrade = grades[ row ][ column ];
67
68       return lowGrade;  // return lowest grade
69    }
70
71    // find maximum grade
72    public int maximum()
73    {
74       // assume first element of grages array is largest
75       int highGrade = grades[ 0 ][ 0 ];
76
77       // loop through rows of grades array
78       for ( int row = 0; row < students; row++ )
79
80          // loop through columns of current row
81          for ( int column = 0; column < exams; column++ )
82
83             // Test if current grade is greater than highGrade.
84             // If so, assign current grade to highGrade.
85             if ( grades[ row ][ column ] > highGrade )
86                highGrade = grades[ row ][ column ];
87
88       return highGrade;  // return highest grade
89    }
90
91    // determine average grade for particular
92    // student (or set of grades)
93    public double average( int setOfGrades[] )
94    {
95       int total = 0;  // initialize total
96
97       // sum grades for one student
98       for ( int count = 0; count < setOfGrades.length; count++ )
99          total += setOfGrades[ count ];
100
```

Fig. 7.16 Example of using double-subscripted arrays (part 2 of 3).

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```
101         // return average of grades
102         return ( double ) total / setOfGrades.length;
103      }
104
105      // build output string
106      public void buildString()
107      {
108         output += "            ";  // used to align column heads
109
110         // create column heads
111         for ( int counter = 0; counter < exams; counter++ )
112            output += "[" + counter + "]   ";
113
114         // create rows/columns of text representing array grades
115         for ( int row = 0; row < students; row++ ) {
116            output += "\ngrades[" + row + "]    ";
117
118            for ( int column = 0; column < exams; column++ )
119               output += grades[ row ][ column ] + "    ";
120         }
121      }
122   }
```

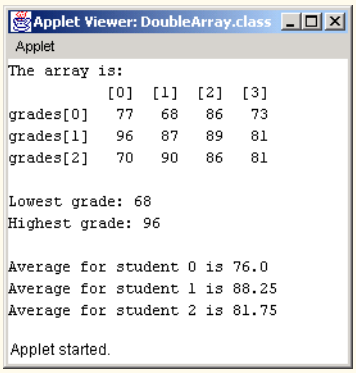

Fig. 7.16 Example of using double-subscripted arrays (part 3 of 3).

Method **average** takes one argument—a single-subscripted array of test results for a particular student. When line 41 calls **average**, the argument is **grades[counter]**, which specifies that a particular row of the double-subscripted array **grades** should be passed to **average**. For example, the argument **grades[1]** represents the four values (a single-subscripted array of grades) stored in the second row of the double-subscripted array **grades**. Remember that, in Java, a double-subscripted array is an array with elements that are single-subscripted arrays. Method **average** calculates the sum of the array elements, divides the total by the number of test results and returns the floating-point result as a **double** value.

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7.10 (Optional Case Study) Thinking About Objects: Collaboration Among Objects

In this section, we concentrate on the collaborations (interactions) among objects. When two objects communicate with each other to accomplish a task, they are said to *collaborate*—objects do this by invoking one another's operations. We say that objects send *messages* to other objects. We explain how messages are sent and received in Java in Section 10.22. A *collaboration* consists of an object of one class sending a particular message to an object of another class.

The message sent by the first object invokes an operation of the second object. In "Thinking About Objects" Section 6.17, we determined many of the operations of the classes in our system. In this section, we concentrate on the messages that invoke these operations. Figure 7.22 is the table of classes and verb phrases from Section 6.17. We have removed all the verb phrases in classes **`Elevator`** and **`Person`** that do not correspond to operations. The remaining phrases are our first estimate of the collaborations in our system. As we proceed through this and the remaining "Thinking About Objects" sections, we will discover additional collaborations.

We examine the list of verb phrases to determine the collaborations in our system. For example, class **`Elevator`** lists the phrase "resets elevator button." To accomplish this task, an object of class **`Elevator`** sends the **`resetButton`** message to an object of class **`ElevatorButton`** (invoking the **`resetButton`** operation of **`ElevatorButton`**). Figure 7.23 lists all the collaborations that can be gleaned from our table of verb phrases. According to Fig. 7.22, the **`Elevator`**[1] rings the **`Bell`** and opens (and closes) the **`ElevatorDoor`**, so we include a **`ringBell`**, **`openDoor`** and **`closeDoor`** message in Fig. 7.23. However, we must consider how the **`FloorDoor`**s open and close. According to the class diagram of Fig. 3.23, **`ElevatorShaft`** is the only class that associates with **`FloorDoor`**. The **`Elevator`** signals its arrival (we assume to the **`ElevatorShaft`**) by sending an **`elevatorArrived`** message. The **`ElevatorShaft`** responds to this message by resetting the appropriate **`FloorButton`** and turning on the appropriate **`Light`**—the **`ElevatorShaft`** sends **`resetButton`** and **`turnOnLight`** messages. At this point in the design, we may assume that the **`Elevator`** also signals its departure—that is, the **`ElevatorShaft`** sends an **`elevatorDeparted`** message to the **`ElevatorShaft`**, which then turns off the appropriate **`Light`** by sending it a **`turnOffLight`** message.

Class	Verb phrases
`Elevator`	Resets elevator button, rings elevator bell, signals its arrival, signals its departure, opens its door, closes its door.
`ElevatorShaft`	Turns off light, turns on light, resets floor button.

Fig. 7.22 Verb phrases for each class exhibiting behaviors in simulation (part 1 of 2).

1. We refer to an object by using that object's class name preceded by an article ("a," "an" or "the")—for example, the **`Elevator`** refers to the object of class **`Elevator`**. Our syntax avoids redundancy—i.e., we avoid repeating the phrase "an object of class...."

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Class	Verb phrases
`Person`	Presses floor button, presses elevator button, rides elevator, enters elevator, exits elevator.
`FloorButton`	Summons (requests) elevator.
`ElevatorButton`	Signals elevator to move to opposite floor.
`FloorDoor`	Signals person to enter elevator (by opening).
`ElevatorDoor`	Signals person to exit elevator (by opening), opens floor door, closes floor door.
`ElevatorModel`	Creates person.

Fig. 7.22 Verb phrases for each class exhibiting behaviors in simulation (part 2 of 2).

An object of class...	Sends the message...	To an object of class...
`Elevator`	`resetButton`	`ElevatorButton`
	`ringBell`	`Bell`
	`elevatorArrived`	`ElevatorShaft`
	`elevatorDeparted`	`ElevatorShaft`
	`openDoor`	`ElevatorDoor`
	`closeDoor`	`ElevatorDoor`
`ElevatorShaft`	`resetButton`	`FloorButton`
	`turnOnLight`	`Light`
	`turnOffLight`	`Light`
`Person`	`pressButton`	`FloorButton, ElevatorButton`
	`enterElevator`	`Elevator`
	`exitElevator`	`Elevator`
`FloorButton`	`requestElevator`	`Elevator`
`ElevatorButton`	`moveElevator`	`Elevator`
`FloorDoor`	`doorOpened`	`Person`
	`doorClosed`	`Person`
`ElevatorDoor`	`doorOpened`	`Person`
	`doorClosed`	`Person`
	`openDoor`	`FloorDoor`
	`closeDoor`	`FloorDoor`

Fig. 7.23 Collaborations in the elevator system.

A **`Person`** may press either a **`FloorButton`** or the **`ElevatorButton`**. A **`Person`** object may enter and exit the **`Elevator`**. Therefore, a **`Person`** may send **`pressButton`**, **`enterElevator`** and **`exitElevator`** messages. A **`FloorButton`** requests, or summons, the **`Elevator`**, so a **`FloorButton`** may send a **`requestElevator`** message. The **`ElevatorButton`** signals the **`Elevator`** to begin moving to the other floor, so the **`ElevatorButton`** may send a **`moveElevator`** message.

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Both a **FloorDoor** and the **ElevatorDoor** inform a **Person** that they have opened or closed, so both objects send **doorOpened** and **doorClosed** messages.[2] Finally, the **ElevatorModel** creates a **Person**, but the **ElevatorModel** cannot send a **personCreated** message, because that **Person** does not yet exist. We discover, in Section 8.6, how to use a special method that creates, or *instantiates*, new objects. This method is referred to as an *constructor*—the **ElevatorModel** will create a **Person** by calling that **Person**'s constructor (which is similar to sending the **personCreated** message).

Lastly, the **ElevatorDoor** must send **openDoor** and **closeDoor** messages to a **FloorDoor** to guarantee that these doors open and close together.

Collaboration Diagrams

Now let us consider the objects that must interact so that people in our simulation can enter and exit the elevator when it arrives on a floor. The UML provides the *collaboration diagram* to model such interactions. Collaboration diagrams are a type of *interaction diagram*; they model the behavioral aspects of the system by providing information about how objects interact. Collaboration diagrams emphasize which objects participate in the interactions. The other type of interaction diagram is the *sequence diagram*, which we present in Chapter 15. Figure 7.24 shows a collaboration diagram that models a person who is pressing a floor button. An object in a collaboration diagram is represented as a rectangle that encloses the object's name. We write object names in the collaboration diagram by using the convention we introduced in the object diagram of Fig. 3.24—objects are written in the form **objectName : ClassName**. In this example, we disregard the object name, because we care only about the object type. Collaborating objects are connected with solid lines, and messages are passed between objects along these lines in the direction shown by arrows. The name of the message, which appears next to the arrow, is the name of a method belonging to the receiving object—think of the name as a "service" that the receiving object (a "server") provides for its sending objects (its "clients").

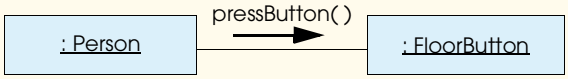

Fig. 7.24 Collaboration diagram of a person pressing a floor button

The arrow in Fig. 7.24 represents a message in the UML and a method—or *synchronous call*—in Java. This arrow indicates that the flow of control is from the sending object to the receiving object—the sending object may not send another message until the receiving object processes the message and returns control to the sending object. For example, in Fig. 7.24, a **Person** calls method **pressButton** of a **FloorButton** and

2. Note that most of the messages perform some specific action on the receiving object; for example, the **Elevator** resets the **ElevatorButton**. However, other messages inform receiving objects of *events* that have already happened; for example, the **FloorDoor** informs the **Person** that the **FloorDoor** has opened. In Section 10.22, we elaborate on the topic of events—for now, however, we proceed as if the two types of messages are indistinguishable.

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may not send another message to an object until **pressButton** has finished and returns control to that **Person**. If our program contains a **FloorButton** object called **firstFloorButton**, and we assume that the **Person** manages the flow of control, the Java code implementation in class **Person** that represents this collaboration diagram is

```
firstFloorButton.pressButton();
```

Figure 7.25 shows a collaboration diagram that models the interactions among objects in the system while objects of class **Person** enter and exit the elevator. The collaboration begins when the **Elevator** arrives on a **Floor**. The number to the left of the message name indicates the order in which the message is passed. The *sequence of messages* in a collaboration diagram progresses in numerical order from least to greatest. In this diagram, the numbering starts with message **1** and ends with message **4.2**. The sequence of passing messages follows a nested structure—for example, message **1.1** is the *first message* nested in message **1**, and message **3.2** is the *second message* nested in message **3**. Message **3.2.1** would be the *first message* nested in message **3.2**. A message may be passed only when all nested messages from the previous message have been passed. For example, in Fig. 7.25, the **Elevator** passes message **4** after message **3**, message **3.1**, message **3.1.1**, message **3.1.1.1**, message **3.2** and message **3.2.1** are passed.

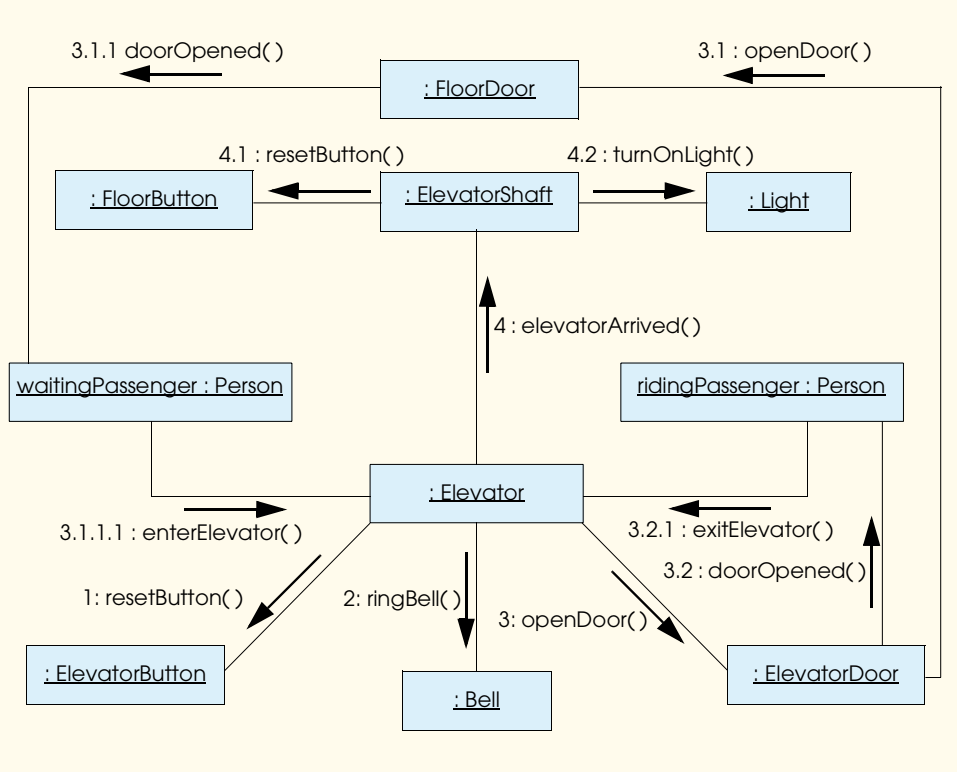

Fig. 7.25 Collaboration diagram for passengers exiting and entering the elevator.

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The **Elevator** sends the **resetButton** message (message **1**) to the **ElevatorButton** to reset the **ElevatorButton**. The **Elevator** sends the **ringBell** message (message **2**) to the **Bell**, then opens the **ElevatorDoor** by passing the **openDoor** message (message **3**). The **ElevatorDoor** then opens the **FloorDoor** by sending an **openDoor** message (message **3.1** at the top of the diagram) to that **FloorDoor**. The **FloorDoor** informs the **waitingPassenger** that the **FloorDoor** has opened (message **3.1.1**), and the **waitingPassenger** enters the **Elevator** (message **3.1.1.1**). The **ElevatorDoor** then informs the **ridingPassenger** that the **ElevatorDoor** has opened (message **3.2**), so that the **ridingPassenger** may exit the **Elevator** (message **3.2.1**). Lastly, the **Elevator** informs the **ElevatorShaft** of the arrival (message **4**), so that the **ElevatorShaft** can reset the **FloorButton** (message **4.1**) and turn on the **Light** (message **4.2**).

Unfortunately, this design creates a problem. According to the diagram, the **waitingPassenger** enters the **Elevator** (message **3.1.1.1**) before the **ridingPassenger** (message **3.2.1**) exits. In "Thinking About Objects" Section 15.12, we apply multithreading, synchronization and active classes to our collaboration diagram, to force the **waitingPassenger** to wait for the **ridingPassenger** to exit the **Elevator**. Before we correct this problem, we modify this diagram to indicate more accurately the message passing in Section 10.22 when we discuss *event handling*.

SUMMARY

- Java stores lists of values in arrays. An array is a contiguous group of related memory locations. These locations are related by the fact that they all have the same name and the same type. To refer to a particular location or element within the array, we specify the name of the array and the subscript (or index or position number) of the element.
- Each array a **length** member that is set to the number of elements in the array at the time the program creates the array object.
- A subscript may be an integer or an integer expression. If a program uses an expression as a subscript, the program evaluates the expression to determine the particular element of the array.
- Java arrays always begin with element 0; thus, it is important to note the difference when referring to the "seventh element of the array" as opposed to "array element seven." The seventh element has a subscript of **6**, while array element seven has a subscript of **7** (actually the eighth element of the array).
- Arrays occupy space in memory and are considered to be objects. Operator **new** must be used to reserve space for an array. For example, the following creates an array of 100 **int** values:

```
int b[] = new int[ 100 ];
```

- When declaring an array, the type of the array and the square brackets can be combined at the beginning of the declaration to indicate that all identifiers in the declaration represent arrays, as in

```
double[] array1, array2;
```

- The elements of an array can be initialized with initializer lists in a declaration and by input.
- Java prevents referencing elements beyond the bounds of an array. If this occurs during program execution, an **ArrayIndexOutOfBoundsException** occurs.
- Constant variables must be initialized with a constant expression before they are used and cannot be modified thereafter.

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- To pass an array to a method, pass the name of the array. To pass a single element of an array to a method, simply pass the name of the array followed by the subscript of the particular element.
- Arrays are passed to methods as references—therefore, the called methods can modify the element values in the caller's original arrays. Single elements of primitive-data-type arrays are passed to methods by value.
- To receive an array argument, the method must specify an array parameter in the parameter list.
- An array can be sorted by using the bubble-sort technique. Several passes of the array are made. On each pass, successive pairs of elements are compared. If a pair is in order (or the values are identical), it is left as is. If a pair is out of order, the values are swapped. For small arrays, the bubble sort is acceptable, but for larger arrays it is inefficient compared to more sophisticated sorting algorithms.
- The linear search compares each element of the array with the search key. If the array is not in any particular order, it is just as likely that the value will be found in the first element as the last. On average, therefore, the program will have to compare the search key with half the elements of the array. Linear search works well for small arrays and is acceptable even for large unsorted arrays.
- For sorted arrays, the binary search eliminates from consideration one half of the elements in the array after each comparison. The algorithm locates the middle element of the array and compares it with the search key. If they are equal, the search key is found and the array subscript of that element is returned. Otherwise, the problem is reduced to searching one half of the array that is still under consideration. In a worst-case scenario, searching a sorted array of 1024 elements will take only 10 comparisons using a binary search.
- Most GUI components have method **`setFont`** to change the font of the text on the GUI component. The method requires a **`Font`** (package **`java.awt`**) object as its argument.
- A **`Font`** object is initialized with three arguments—a **`String`** representing the name of the font, an **`int`** representing the style of the font and an **`int`** representing the point size of the font. The style can be **`Font.PLAIN`**, **`Font.BOLD`**, **`Font.ITALIC`** or **`Font.BOLD + Font.ITALIC`**. The point size represents the size of the font—there are 72 points to an inch. The actual screen size may vary based on the size of the screen and the screen resolution.
- Arrays may be used to represent tables of values consisting of information arranged in rows and columns. To identify a particular element of a table, two subscripts are specified: The first identifies the row in which the element is contained, and the second identifies the column in which the element is contained. Tables or arrays that require two subscripts to identify a particular element are called double-subscripted arrays.
- A double-subscripted array can be initialized with an initializer list of the form

  arrayType arrayName **`[][] = { {`** *row1 sublist* **`}, {`** *row2 sublist* **`}, ... };**

- To dynamically create an array with a fixed number of rows and columns, use

  arrayType arrayName **`[][] = new`** *arrayType* **`[`** *numRows* **`][`** *numColumns* **`];`**

- To pass one row of a double-subscripted array to a method that receives a single-subscripted array, simply pass the name of the array followed by only the row subscript.

TERMINOLOGY

`a[ i ]`
`a[ i ][ j ]`
array
array initializer list
binary search of an array
bounds checking
bubble sort
column subscript
constant variable
declare an array
double-subscripted array
element of an array

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`final`
`Font` class from **`java.awt`**
`Font.BOLD`
`Font.ITALIC`
`Font.PLAIN`
index
initialize an array
initializer
linear search of an array
lvalue
m-by-n array
multiple-subscripted array
name of an array
named constant
off-by-one error
pass of a bubble sort
pass-by-reference
pass-by-value
passing arrays to methods
position number
row subscript
search key
searching an array
`setFont` method
single-subscripted array
sinking sort
sorting
sorting an array
square brackets, **`[]`**
subscript
table of values
tabular format
temporary area for exchange of values
value of an element
zeroth element

SELF-REVIEW EXERCISES

7.1 Fill in the blank(s) in each of the following statements:
a) Lists and tables of values can be stored in _____.
b) The elements of an array are related by the fact that they have the same _____ and _____.
c) The number used to refer to a particular element of an array is called its _____.
d) The process of placing the elements of an array in order is called _____ the array.
e) Determining if an array contains a certain key value is called _____ the array.
f) An array that uses two subscripts is referred to as a _____ array.

7.2 State whether each of the following is *true* or *false*. If *false*, explain why.
a) An array can store many different types of values.
b) An array subscript should normally be of data type **`float`**.
c) An individual array element that is passed to a method and modified in that method will contain the modified value when the called method completes execution.

7.3 Answer the following questions regarding an array called **`fractions`**:
a) Define a constant variable **`ARRAY_SIZE`** initialized to 10.
b) Declare an array with **`ARRAY_SIZE`** elements of type **`float`** and initialize the elements to **`0`**.
c) Name the fourth element of the array.
d) Refer to array element 4.
e) Assign the value **`1.667`** to array element 9.
f) Assign the value **`3.333`** to the seventh element of the array.
g) Sum all the elements of the array using a **`for`** repetition structure. Define the integer variable **`x`** as a control variable for the loop.

7.4 Answer the following questions regarding an array called **`table`**:
a) Declare and create the array as an integer array and with 3 rows and 3 columns. Assume the constant variable **`ARRAY_SIZE`** has been defined to be 3.
b) How many elements does the array contain?
c) Use a **`for`** repetition structure to initialize each element of the array to the sum of its subscripts. Assume the integer variables **`x`** and **`y`** are declared as control variables.

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7.5 Find the error in each of the following program segments and correct the error:

a)
```
final int ARRAY_SIZE = 5;
ARRAY_SIZE = 10;
```

b) Assume
```
int b[] = new int[ 10 ];
for ( int i = 0; i <= b.length; i++ )
   b[ i ] = 1;
```

c) Assume
```
int a[][] = { { 1, 2 }, { 3, 4 } };
a[ 1, 1 ] = 5;
```

ANSWERS TO SELF-REVIEW EXERCISES

7.1 a) arrays. b) name, type. c) subscript (or index or position number). d) sorting. e) searching. f) double-subscripted (or two-dimensional).

7.2 a) False. An array can store only values of the same type.

b) False. An array subscript must be an integer or an integer expression.

c) False for individual primitive-data-type elements of an array because they are passed by value. If a reference to an array is passed, then modifications to the array elements are reflected in the original. Also, an individual element of a nonprimitive type is passed by reference, and changes to the object will be reflected in the original array element.

7.3 a)
```
final int ARRAY_SIZE = 10;
```

b)
```
float fractions[] = new float[ ARRAY_SIZE ];
```

c)
```
fractions[ 3 ]
```

d)
```
fractions[ 4 ]
```

e)
```
fractions[ 9 ] = 1.667;
```

f)
```
fractions[ 6 ] = 3.333;
```

g)
```
float total = 0;
for ( int x = 0; x < fractions.length; x++ )
   total += fractions[ x ];
```

7.4 a)
```
int table[][] = new int[ ARRAY_SIZE ][ ARRAY_SIZE ];
```

b) Nine.

c)
```
for ( int x = 0; x < table.length; x++ )
   for ( int y = 0; y < table[ x ].length; y++ )
      table[ x ][ y ] = x + y;
```

7.5 The solutions to Exercise 7.5 are as follows:

a) Error: Assigning a value to a constant variable after it has been initialized.
Correction: Assign the correct value to the constant variable in a **`final int ARRAY_SIZE`** declaration or create another variable.

b) Error: Referencing an array element outside the bounds of the array (**`b[10]`**).
Correction: Change the **`<=`** operator to **`<`**.

c) Error: Array subscripting performed incorrectly.
Correction: Change the statement to **`a[ 1 ][ 1 ] = 5;`**.

EXERCISES

7.6 Fill in the blanks in each of the following:

a) Java stores lists of values in _____.

b) The elements of an array are related by the fact that they _____.

c) When referring to an array element, the position number contained within brackets is called a _____.

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d) The names of the four elements of array **p** are _____, _____, _____ and _____.
e) Naming an array, stating its type and specifying the number of dimensions in the array is called _____ the array.
f) The process of placing the elements of an array into either ascending or descending order is called _____.
g) In a double-subscripted array, the first subscript identifies the _____ of an element and the second subscript identifies the _____ of an element.
h) An m-by-n array contains _____ rows, _____ columns and _____ elements.
i) The name of the element in row 3 and column 5 of array **d** is _____.

7.7 State whether each of the following is *true* or *false*. If *false*, explain why.
a) To refer to a particular location or element within an array, we specify the name of the array and the value of the particular element.
b) An array declaration reserves space for the array.
c) To indicate that 100 locations should be reserved for integer array **p**, the programmer writes the declaration

```
p[ 100 ];
```

d) A Java program that initializes the elements of a 15-element array to zero must contain at least one **for** statement.
e) A Java program that totals the elements of a double-subscripted array must contain nested **for** statements.

7.8 Write Java statements to accomplish each of the following:
a) Display the value of the seventh element of character array **f**.
b) Initialize each of the five elements of single-subscripted integer array **g** to **8**.
c) Total the elements of floating-point array **c** of 100 elements.
d) Copy 11-element array **a** into the first portion of array **b**, containing 34 elements.
e) Determine and print the smallest and largest values contained in 99-element floating-point array **w**.

7.9 Consider a 2-by-3 integer array **t**.
a) Write a statement that declares and creates **t**.
b) How many rows does **t** have?
c) How many columns does **t** have?
d) How many elements does **t** have?
e) Write the names of all the elements in the second row of **t**.
f) Write the names of all the elements in the third column of **t**.
g) Write a single statement that sets the element of **t** in row 1 and column 2 to zero.
h) Write a series of statements that initializes each element of **t** to zero. Do not use a repetition structure.
i) Write a nested **for** structure that initializes each element of **t** to zero.
j) Write a nested **for** structure that inputs the values for the elements of **t** from the keyboard.
k) Write a series of statements that determines and prints the smallest value in array **t**.
l) Write a statement that displays the elements of the first row of **t**.
m) Write a statement that totals the elements of the fourth column of **t**.
n) Write a series of statements that prints the array **t** in neat, tabular format. List the column subscripts as headings across the top and list the row subscripts at the left of each row.

7.10 Use a single-subscripted array to solve the following problem: A company pays its salespeople on a commission basis. The salespeople receive $200 per week plus 9% of their gross sales for

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that week. For example, a salesperson who grosses $5000 in sales in a week receives $200 plus 9% of $5000 or a total of $650. Write an applet (using an array of counters) that determines how many of the salespeople earned salaries in each of the following ranges (assume that each salesperson's salary is truncated to an integer amount):

a) $200-$299
b) $300-$399
c) $400-$499
d) $500-$599
e) $600-$699
f) $700-$799
g) $800-$899
h) $900-$999
i) $1000 and over

The applet should use the GUI techniques introduced in Chapter 6. Display the results in a **`JTextArea`**. Use **`JTextArea`** method **`setText`** to update the results after each value input by the user.

7.11 The bubble sort presented in Fig. 7.11 is inefficient for large arrays. Make the following simple modifications to improve the performance of the bubble sort:

a) After the first pass, the largest number is guaranteed to be in the highest-numbered element of the array; after the second pass, the two highest numbers are "in place"; and so on. Instead of making nine comparisons on every pass, modify the bubble sort to make eight comparisons on the second pass, seven on the third pass and so on.
b) The data in the array may already be in the proper order or near-proper order, so why make nine passes if fewer will suffice? Modify the sort to check at the end of each pass if any swaps have been made. If none have been made, the data must already be in the proper order, so the program should terminate. If swaps have been made, at least one more pass is needed.

7.12 Write statements that perform the following single-subscripted array operations:

a) Set the 10 elements of integer array **`counts`** to zeros.
b) Add 1 to each of the 15 elements of integer array **`bonus`**.
c) Print the five values of integer array **`bestScores`** in column format.

7.13 Use a single-subscripted array to solve the following problem: Write an applet that inputs 20 numbers, each of which is between 10 and 100, inclusive. As each number is read, display it only if it is not a duplicate of a number already read. Provide for the "worst case" in which all 20 numbers are different. Use the smallest possible array to solve this problem. The applet should use the GUI techniques introduced in Chapter 6. Display the results in a **`JTextArea`**. Use **`JTextArea`** method **`setText`** to update the results after each value input by the user.

7.14 Label the elements of 3-by-5 double-subscripted array **`sales`** to indicate the order in which they are set to zero by the following program segment:

```
for ( int row = 0; row < sales.length; row++ )

   for ( int col = 0; col < sales[ row ].length; col++ )

      sales[ row ][ col ] = 0;
```

7.15 Write an applet to simulate the rolling of two dice. The program should use **`Math.random`** to roll the first die and should use **`Math.random`** again to roll the second die. The sum of the two values should then be calculated. [*Note*: Each die can show an integer value from 1 to 6, so the sum of the values will vary from 2 to 12, with 7 being the most frequent sum and 2 and 12 being the least frequent sums. Figure 7.26 shows the 36 possible combinations of the two dice. Your program should

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	1	2	3	4	5	6
1	2	3	4	5	6	7
2	3	4	5	6	7	8
3	4	5	6	7	8	9
4	5	6	7	8	9	10
5	6	7	8	9	10	11
6	7	8	9	10	11	12

Fig. 7.26 The 36 possible outcomes of rolling two dice.

roll the dice 36,000 times. Use a single-subscripted array to tally the numbers of times each possible sum appears. Display the results in a **JTextArea** in tabular format. Also, determine whether the totals are reasonable (i.e., there are six ways to roll a 7, so approximately one sixth of all the rolls should be 7). The applet should use the GUI techniques introduced in Chapter 6. Provide a **JButton** to allow the user of the applet to roll the dice another 36,000 times. The applet should reset the elements of the single-subscripted array to 0 before rolling the dice again.

7.16 What does the program of Fig. 7.27 do?

```
1  // Exercise 7.16: WhatDoesThisDo.java
2
3  // Java core packages
4  import java.awt.*;
5
6  // Java extension packages
7  import javax.swing.*;
8
9  public class WhatDoesThisDo extends JApplet {
10    int result;
11
12    public void init()
13    {
14       int array[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
15
16       result = whatIsThis( array, array.length );
17
18       Container container = getContentPane();
19       JTextArea output = new JTextArea();
20       output.setText( "Result is: " + result );
21       container.add( output );
22    }
23
24    public int whatIsThis( int array2[], int size )
25    {
26       if ( size == 1 )
27          return array2[ 0 ];
```

Fig. 7.27 Determine what this program does.

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```
28         else
29            return array2[ size - 1 ] +
30               whatIsThis( array2, size - 1 );
31      }
32   }
```

Fig. 7.27 Determine what this program does.

7.17 Write a program that runs 1000 games of craps (Fig. 6.9) and answers the following questions:

a) How many games are won on the first roll, second roll, …, twentieth roll and after the twentieth roll?
b) How many games are lost on the first roll, second roll, …, twentieth roll and after the twentieth roll?
c) What are the chances of winning at craps? [*Note*: You should discover that craps is one of the fairest casino games. What do you suppose this means?]
d) What is the average length of a game of craps?
e) Do the chances of winning improve with the length of the game?

7.18 (*Airline Reservations System*) A small airline has just purchased a computer for its new automated reservations system. You have been asked to program the new system. You are to write an applet to assign seats on each flight of the airline's only plane (capacity: 10 seats).

Your program should display the following alternatives:

```
Please type 1 for "smoking"
Please type 2 for "nonsmoking"
```

If the person types 1, your program should assign a seat in the smoking section (seats 1-5). If the person types 2, your program should assign a seat in the nonsmoking section (seats 6-10). Your program should then print a boarding pass indicating the person's seat number and whether it is in the smoking or nonsmoking section of the plane.

Use a single-subscripted array of primitive type **`boolean`** to represent the seating chart of the plane. Initialize all the elements of the array to **`false`** to indicate that all seats are empty. As each seat is assigned, set the corresponding elements of the array to **`true`** to indicate that the seat is no longer available.

Your program should, of course, never assign a seat that has already been assigned. When the smoking section is full, your program should ask the person if it is acceptable to be placed in the nonsmoking section (and vice versa). If yes, make the appropriate seat assignment. If no, print the message **`"Next flight leaves in 3 hours."`**

7.19 What does the program of Fig. 7.28 do?

```
1  // Exercise 7.19: WhatDoesThisDo2.java
2
3  // Java core packages
4  import java.awt.*;
5
6  // Java extension packages
7  import javax.swing.*;
8
```

Fig. 7.28 Determine what this program does.

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```
 9  public class WhatDoesThisDo2 extends JApplet {
10
11     public void init()
12     {
13        int array[] = { 1, 2, 3, 4, 5, 6, 7, 8, 9, 10 };
14        JTextArea outputArea = new JTextArea();
15
16        someFunction( array, 0, outputArea );
17
18        Container container = getContentPane();
19        container.add( outputArea );
20     }
21
22     public void someFunction( int array2[], int x, JTextArea out )
23     {
24        if ( x < array2.length ) {
25           someFunction( array2, x + 1, out );
26           out.append( array2[ x ] + "   " );
27        }
28     }
29  }
```

Fig. 7.28 Determine what this program does.

7.20 Use a double-subscripted array to solve the following problem. A company has four salespeople (1 to 4) who sell five different products (1 to 5). Once a day, each salesperson passes in a slip for each different type of product sold. Each slip contains the following:

a) The salesperson number
b) The product number
c) The total dollar value of that product sold that day

Thus, each salesperson passes in between 0 and 5 sales slips per day. Assume that the information from all of the slips for last month is available. Write an applet that will read all this information for last month's sales and summarize the total sales by salesperson by product. All totals should be stored in the double-subscripted array **`sales`**. After processing all the information for last month, display the results in tabular format with each of the columns representing a particular salesperson and each of the rows representing a particular product. Cross total each row to get the total sales of each product for last month; cross total each column to get the total sales by salesperson for last month. Your tabular printout should include these cross totals to the right of the totaled rows and to the bottom of the totaled columns. Display the results in a **`JTextArea`**.

7.21 (*Turtle Graphics*) The Logo language, which is popular among young computer users, made the concept of *turtle graphics* famous. Imagine a mechanical turtle that walks around the room under the control of a Java program. The turtle holds a pen in one of two positions, up or down. While the pen is down, the turtle traces out shapes as it moves; while the pen is up, the turtle moves about freely without writing anything. In this problem you will simulate the operation of the turtle and create a computerized sketchpad as well.

Use a 20-by-20 array **`floor`** that is initialized to zeros. Read commands from an array that contains them. Keep track of the current position of the turtle at all times and whether the pen is currently up or down. Assume that the turtle always starts at position 0,0 of the floor with its pen up. The set of turtle commands your program must process are shown in Fig. 7.29.

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Command	Meaning
`1`	Pen up
`2`	Pen down
`3`	Turn right
`4`	Turn left
`5,10`	Move forward 10 spaces (or a number other than 10)
`6`	Print the 20-by-20 array
`9`	End of data (sentinel)

Fig. 7.29 Turtle graphics commands.

Suppose that the turtle is somewhere near the center of the floor. The following "program" would draw and print a 12-by-12 square, leaving the pen in the up position:

```
2
5,12
3
5,12
3
5,12
3
5,12
1
6
9
```

As the turtle moves with the pen down, set the appropriate elements of array **`floor`** to **`1`**s. When the **`6`** command (print) is given, wherever there is a **`1`** in the array, display an asterisk or some other character you choose. Wherever there is a zero, display a blank. Write a Java applet to implement the turtle graphics capabilities discussed here. The applet should display the turtle graphics in a **`JTextArea`**, using Monospaced font. Write several turtle graphics programs to draw interesting shapes. Add other commands to increase the power of your turtle graphics language.

7.22 (*Knight's Tour*) One of the more interesting puzzlers for chess buffs is the Knight's Tour problem, originally proposed by the mathematician Euler. The question is this: Can the chess piece called the knight move around an empty chessboard and touch each of the 64 squares once and only once? We study this intriguing problem in depth here.

The knight makes L-shaped moves (over two in one direction and then over one in a perpendicular direction). Thus, from a square in the middle of an empty chessboard, the knight can make eight different moves (numbered 0 through 7) as shown in Fig. 7.30.

a) Draw an 8-by-8 chessboard on a sheet of paper and attempt a Knight's Tour by hand. Put a **`1`** in the first square you move to, a **`2`** in the second square, a **`3`** in the third, etc. Before starting the tour, estimate how far you think you will get, remembering that a full tour consists of 64 moves. How far did you get? Was this close to your estimate?

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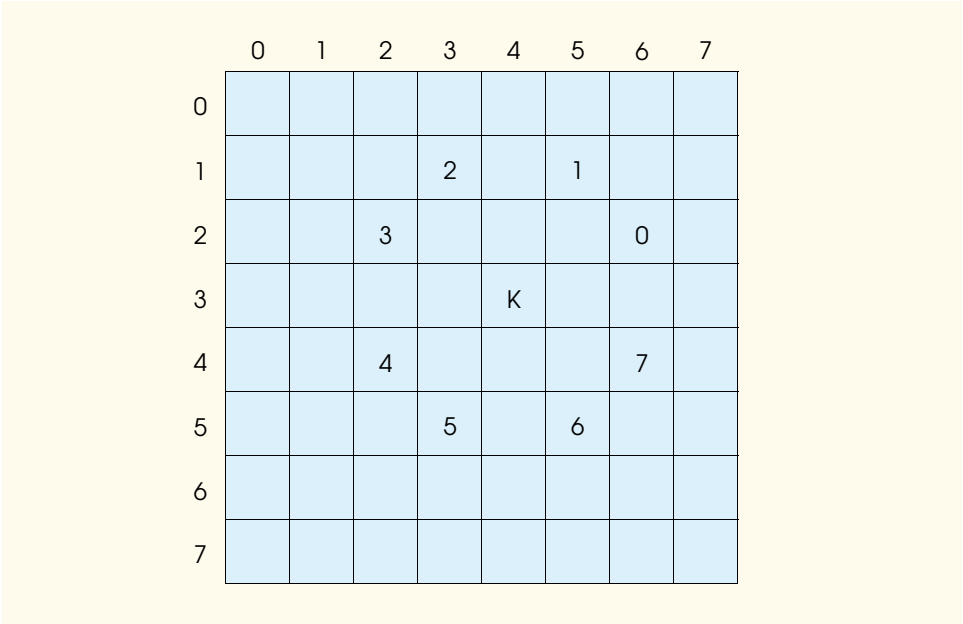

Fig. 7.30 The eight possible moves of the knight.

b) Now let us develop an applet that will move the knight around a chessboard. The board is represented by an 8-by-8 double-subscripted array **board**. Each of the squares is initialized to zero. We describe each of the eight possible moves in terms of both their horizontal and vertical components. For example, a move of type 0 as shown in Fig. 7.30 consists of moving two squares horizontally to the right and one square vertically upward. Move 2 consists of moving one square horizontally to the left and two squares vertically upward. Horizontal moves to the left and vertical moves upward are indicated with negative numbers. The eight moves may be described by two single-subscripted arrays, **horizontal** and **vertical**, as follows:

```
horizontal[ 0 ] = 2
horizontal[ 1 ] = 1
horizontal[ 2 ] = -1
horizontal[ 3 ] = -2
horizontal[ 4 ] = -2
horizontal[ 5 ] = -1
horizontal[ 6 ] = 1
horizontal[ 7 ] = 2

vertical[ 0 ] = -1
vertical[ 1 ] = -2
vertical[ 2 ] = -2
vertical[ 3 ] = -1
vertical[ 4 ] = 1
vertical[ 5 ] = 2
vertical[ 6 ] = 2
vertical[ 7 ] = 1
```

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Let the variables **currentRow** and **currentColumn** indicate the row and column of the knight's current position. To make a move of type **moveNumber**, where **moveNumber** is between 0 and 7, your program uses the statements

```
currentRow += vertical[ moveNumber ];
currentColumn += horizontal[ moveNumber ];
```

Keep a counter that varies from **1** to **64**. Record the latest count in each square the knight moves to. Test each potential move to see if the knight already visited that square. Test every potential move to ensure that the knight does not land off the chessboard. Write a program to move the knight around the chessboard. Run the program. How many moves did the knight make?

c) After attempting to write and run a Knight's Tour program, you have probably developed some valuable insights. We will use these to develop a *heuristic* (or strategy) for moving the knight. Heuristics do not guarantee success, but a carefully developed heuristic greatly improves the chance of success. You may have observed that the outer squares are more troublesome than the squares nearer the center of the board. In fact, the most troublesome or inaccessible squares are the four corners.

Intuition may suggest that you should attempt to move the knight to the most troublesome squares first and leave open those that are easiest to get to so when the board gets congested near the end of the tour there will be a greater chance of success.

We could develop an "accessibility heuristic" by classifying each of the squares according to how accessible they are, then always moving the knight (using the knight's L-shaped moves) to the most inaccessible square. We label a double-subscripted array **accessibility** with numbers indicating from how many squares each particular square is accessible. On a blank chessboard, each center square is rated as **8**, each corner square is rated as **2** and the other squares have accessibility numbers of **3**, **4** or **6** as follows:

```
2  3  4  4  4  4  3  2
3  4  6  6  6  6  4  3
4  6  8  8  8  8  6  4
4  6  8  8  8  8  6  4
4  6  8  8  8  8  6  4
4  6  8  8  8  8  6  4
3  4  6  6  6  6  4  3
2  3  4  4  4  4  3  2
```

Write a version of the Knight's Tour using the accessibility heuristic. The knight should always move to the square with the lowest accessibility number. In case of a tie, the knight may move to any of the tied squares. Therefore, the tour may begin in any of the four corners. [*Note*: As the knight moves around the chessboard, your program should reduce the accessibility numbers as more squares become occupied. In this way, at any given time during the tour, each available square's accessibility number will remain equal to precisely the number of squares from which that square may be reached.] Run this version of your program. Did you get a full tour? Modify the program to run 64 tours, one starting from each square of the chessboard. How many full tours did you get?

d) Write a version of the Knight's Tour program that, when encountering a tie between two or more squares, decides what square to choose by looking ahead to those squares reachable from the "tied" squares. Your program should move to the square for which the next move would arrive at a square with the lowest accessibility number.

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7.23 (*Knight's Tour: Brute Force Approaches*) In Exercise 7.22, we developed a solution to the Knight's Tour problem. The approach used, called the "accessibility heuristic," generates many solutions and executes efficiently.

As computers continue increasing in power, we will be able to solve more problems with sheer computer power and relatively unsophisticated algorithms. Let us call this approach "brute force" problem solving.

a) Use random number generation to enable the knight to walk around the chessboard (in its legitimate L-shaped moves, of course) at random. Your program should run one tour and print the final chessboard. How far did the knight get?

b) Most likely, the preceding program produced a relatively short tour. Now modify your program to attempt 1000 tours. Use a single-subscripted array to keep track of the number of tours of each length. When your program finishes attempting the 1000 tours, it should print this information in neat tabular format. What was the best result?

c) Most likely, the preceding program gave you some "respectable" tours, but no full tours. Now "pull all the stops out" and simply let your program run until it produces a full tour. (*Caution*: This version of the program could run for hours on a powerful computer.) Once again, keep a table of the number of tours of each length and print this table when the first full tour is found. How many tours did your program attempt before producing a full tour? How much time did it take?

d) Compare the brute force version of the Knight's Tour with the accessibility-heuristic version. Which required a more careful study of the problem? Which algorithm was more difficult to develop? Which required more computer power? Could we be certain (in advance) of obtaining a full tour with the accessibility-heuristic approach? Could we be certain (in advance) of obtaining a full tour with the brute force approach? Argue the pros and cons of brute force problem solving in general.

7.24 (*Eight Queens*) Another puzzler for chess buffs is the Eight Queens problem. Simply stated: Is it possible to place eight queens on an empty chessboard so that no queen is "attacking" any other, i.e., no two queens are in the same row, in the same column or along the same diagonal? Use the thinking developed in Exercise 7.22 to formulate a heuristic for solving the Eight Queens problem. Run your program. (*Hint*: It is possible to assign a value to each square of the chessboard indicating how many squares of an empty chessboard are "eliminated" if a queen is placed in that square. Each of the corners would be assigned the value 22, as in Figure 7.31.) Once these "elimination numbers" are placed in all 64 squares, an appropriate heuristic might be: Place the next queen in the square with the smallest elimination number. Why is this strategy intuitively appealing?

7.25 (*Eight Queens: Brute Force Approaches*) In this exercise, you will develop several brute force approaches to solving the Eight Queens problem introduced in Exercise 7.24.

a) Solve the Eight Queens exercise, using the random brute force technique developed in Exercise 7.23.

b) Use an exhaustive technique (i.e., try all possible combinations of eight queens on the chessboard).

c) Why do you suppose the exhaustive brute force approach may not be appropriate for solving the Knight's Tour problem?

d) Compare and contrast the random brute force and exhaustive brute force approaches.

7.26 (*Knight's Tour: Closed Tour Test*) In the Knight's Tour, a full tour occurs when the knight makes 64 moves touching each square of the chessboard once and only once. A closed tour occurs when the 64th move is one move away from the square in which the knight started the tour. Modify the program you wrote in Exercise 7.22 to test for a closed tour if a full tour has occurred.

7.27 (*The Sieve of Eratosthenes*) A prime integer is any integer that is evenly divisible only by itself and 1. The Sieve of Eratosthenes is a method of finding prime numbers. It operates as follows:

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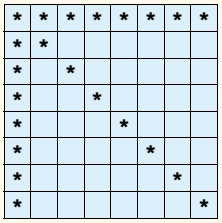

Fig. 7.31 The 22 squares eliminated by placing a queen in the upper left corner.

a) Create a primitive type **boolean** array with all elements initialized to **true**. Array elements with prime subscripts will remain **true**. All other array elements will eventually be set to **false**.
b) Starting with array subscript 2 (subscript 1 must be prime), determine whether a given element is **true**. If so, loop through the remainder of the array and set to **false** every element whose subscript is a multiple of the subscript for the element with value **true**. Then, continue the process with the next element with value **true**. For array subscript 2, all elements beyond element 2 in the array that have subscripts which are multiples of 2 will be set to **false** (subscripts 4, 6, 8, 10, etc.); for array subscript 3, all elements beyond element 3 in the array that have subscripts which are multiples of 3 will be set to **false** (subscripts 6, 9, 12, 15, etc.); and so on.

When this process is complete, the array elements that are still **true** indicate that the subscript is a prime number. These subscripts can be displayed. Write a program that uses an array of 1000 elements to determine and print the prime numbers between 1 and 999. Ignore element 0 of the array.

7.28 (*Bucket Sort*) A bucket sort begins with a single-subscripted array of positive integers to be sorted and a double-subscripted array of integers with rows subscripted from 0 to 9 and columns subscripted from 0 to *n* - 1, where *n* is the number of values in the array to be sorted. Each row of the double-subscripted array is referred to as a bucket. Write an applet containing a method called **bucketSort** that takes an integer array as an argument and performs as follows:

a) Place each value of the single-subscripted array into a row of the bucket array based on the value's ones digit. For example, 97 is placed in row 7, 3 is placed in row 3 and 100 is placed in row 0. This is called a "distribution pass."
b) Loop through the bucket array row by row and copy the values back to the original array. This is called a "gathering pass." The new order of the preceding values in the single-subscripted array is 100, 3 and 97.
c) Repeat this process for each subsequent digit position (tens, hundreds, thousands, etc.).

On the second pass, 100 is placed in row 0, 3 is placed in row 0 (because 3 has no tens digit) and 97 is placed in row 9. After the gathering pass, the order of the values in the single-subscripted array is 100, 3 and 97. On the third pass, 100 is placed in row 1, 3 is placed in row 0 and 97 is placed in row 0 (after the 3). After the last gathering pass, the original array is now in sorted order.

Note that the double-subscripted array of buckets is ten times the size of the integer array being sorted. This sorting technique provides better performance than a bubble sort, but requires much more memory. The bubble sort requires space for only one additional element of data. This is an example of the space-time trade-off: The bucket sort uses more memory than the bubble sort, but performs better. This version of the bucket sort requires copying all the data back to the original array on each pass. Another possibility is to create a second double-subscripted bucket array and repeatedly swap the data between the two bucket arrays.

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RECURSION EXERCISES

7.29 (*Selection Sort*) A selection sort searches an array looking for the smallest element in the array, then swaps that element with the first element of the array. The process is repeated for the subarray beginning with the second element. Each pass of the array places one element in its proper location. For an array of *n* elements, *n* - 1 passes must be made, and for each subarray, *n* - 1 comparisons must be made to find the smallest value. When the subarray being processed contains one element, the array is sorted. Write recursive method **`selectionSort`** to perform this algorithm.

7.30 (*Palindromes*) A palindrome is a string that is spelled the same way forward and backward. Some examples of palindromes are "radar," "able was i ere i saw elba" and (if blanks are ignored) "a man a plan a canal panama." Write a recursive method **`testPalindrome`** that returns **`boolean`** value **`true`** if the string stored in the array is a palindrome and **`false`** otherwise. The method should ignore spaces and punctuation in the string. [Hint: Use **`String`** method **`toCharArray`**, which takes no arguments, to get a **`char`** array containing the characters in the **`String`**. Then, pass the array to method testPalindrome.]

7.31 (*Linear Search)* Modify Figure 7.12 to use recursive method **`linearSearch`** to perform a linear search of the array. The method should receive an integer array, the array size and the search key as arguments. If the search key is found, return the array subscript; otherwise, return –1.

7.32 (*Binary Search*) Modify the program of Figure 7.13 to use a recursive method **`binarySearch`** to perform the binary search of the array. The method should receive an integer array and the starting subscript and ending subscript as arguments. If the search key is found, return the array subscript; otherwise, return –1.

7.33 (*Eight Queens)* Modify the Eight Queens program you created in Exercise 7.24 to solve the problem recursively.

7.34 (*Print an array*) Write a recursive method **`printArray`** that takes an array of **`int`** values and the size of the array as arguments and returns nothing. The method should stop processing and return when it receives an array of size 0.

7.35 (*Print a string backward*) Write a recursive method **`stringReverse`** that takes a character array containing a string as an argument, prints the string backward and returns nothing.

7.36 (*Find the minimum value in an array*) Write a recursive method **`recursiveMinimum`** that takes an integer array and the array size as arguments and returns the smallest element of the array. The method should stop processing and return when it receives an array of one element.

7.37 (*Quicksort*) In the examples and exercises of this chapter, we discussed the sorting techniques bubble sort, bucket sort and selection sort. We now present the recursive sorting technique called Quicksort. The basic algorithm for a single-subscripted array of values is as follows:

a) *Partitioning Step*: Take the first element of the unsorted array and determine its final location in the sorted array (i.e., all values to the left of the element in the array are less than the element, and all values to the right of the element in the array are greater than the element). We now have one element in its proper location and two unsorted subarrays.

b) *Recursive Step*: Perform step 1 on each unsorted subarray.

Each time step 1 is performed on a subarray, another element is placed in its final location of the sorted array and two unsorted subarrays are created. When a subarray consists of one element, it must be sorted therefore, that element is in its final location.

The basic algorithm seems simple enough, but how do we determine the final position of the first element of each subarray? As an example, consider the following set of values (the element in bold is the partitioning element—it will be placed in its final location in the sorted array):

37 2 6 4 89 8 10 12 68 45

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a) Starting from the rightmost element of the array, compare each element to **37** until an element less than **37** is found, then swap **37** and that element. The first element less than **37** is 12, so **37** and 12 are swapped. The new array is

12 2 6 4 89 8 10 **37** 68 45

Element 12 is in italic to indicate that it was just swapped with **37**.

b) Starting from the left of the array, but beginning with the element after 12, compare each element to **37** until an element greater than **37** is found, then swap **37** and that element. The first element greater than **37** is 89, so **37** and 89 are swapped. The new array is

12 2 6 4 **37** 8 10 *89* 68 45

c) Starting from the right, but beginning with the element before 89, compare each element to **37** until an element less than **37** is found, then swap **37** and that element. The first element less than **37** is 10, so **37** and 10 are swapped. The new array is

12 2 6 4 *10* 8 **37** 89 68 45

d) Starting from the left, but beginning with the element after 10, compare each element to **37** until an element greater than **37** is found, then swap **37** and that element. There are no more elements greater than **37**, so when we compare **37** to itself we know that **37** has been placed in its final location of the sorted array.

Once the partition has been applied on the previous array, there are two unsorted subarrays. The subarray with values less than 37 contains 12, 2, 6, 4, 10 and 8. The subarray with values greater than 37 contains 89, 68 and 45. The sort continues with both subarrays being partitioned in the same manner as the original array.

Based on the preceding discussion, write recursive method **`quickSort`** to sort a single-subscripted integer array. The method should receive as arguments an integer array, a starting subscript and an ending subscript. Method **`partition`** should be called by **`quickSort`** to perform the partitioning step.

7.38 (*Maze Traversal*) The following grid of **#**s and dots (**.**) is a double-subscripted array representation of a maze.

```
# # # # # # # # # # # #
# . . . # . . . . . . #
. . # . # . # # # # . #
# # # . # . . . . # . #
# . . . . # # # . # . .
# # # # . # . # . # . #
# . . # . # . # . # . #
# # . # . # . # . # . #
# . . . . . . . . # . #
# # # # # # . # # # . #
# . . . . . . # . . . #
# # # # # # # # # # # #
```

In the preceding double-subscripted array, the **#**s represent the walls of the maze, and the dots represent squares in the possible paths through the maze. Moves can be made only to a location in the array that contains a dot.

There is a simple algorithm for walking through a maze that guarantees finding the exit (assuming there is an exit). If there is not an exit, you will arrive at the starting location again. Place your right hand on the wall to your right and begin walking forward. Never remove your hand from the wall. If the maze turns to the right, you follow the wall to the right. As long as you do not remove your hand

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from the wall, eventually you will arrive at the exit of the maze. There may be a shorter path than the one you have taken, but you are guaranteed to get out of the maze if you follow the algorithm.

Write recursive method **mazeTraverse** to walk through the maze. The method should receive as arguments a 12-by-12 character array representing the maze and the starting location of the maze. As **mazeTraverse** attempts to locate the exit from the maze, it should place the character **X** in each square in the path. The method should display the maze after each move so the user can watch as the maze is solved.

7.39 (*Generating Mazes Randomly*) Write a method **mazeGenerator** that takes as an argument a double-subscripted 12-by-12 character array and randomly produces a maze. The method should also provide the starting and ending locations of the maze. Try your method **mazeTraverse** from Exercise 7.38, using several randomly generated mazes.

7.40 (*Mazes of Any Size*) Generalize methods **mazeTraverse** and **mazeGenerator** of Exercise 7.38 and Exercise 7.39 to process mazes of any width and height.

7.41 (*Simulation: The Tortoise and the Hare*) In this problem, you will recreate one of the truly great moments in history, namely the classic race of the tortoise and the hare. You will use random number generation to develop a simulation of this memorable event.

Our contenders begin the race at "square 1" of 70 squares. Each square represents a possible position along the race course. The finish line is at square 70. The first contender to reach or pass square 70 is rewarded with a pail of fresh carrots and lettuce. The course weaves its way up the side of a slippery mountain, so occasionally the contenders lose ground.

There is a clock that ticks once per second. With each tick of the clock, your applet should adjust the position of the animals according to the rules in Fig. 7.32

Use variables to keep track of the positions of the animals (i.e., position numbers are 1–70). Start each animal at position 1 (i.e., the "starting gate"). If an animal slips left before square 1, move the animal back to square 1.

Generate the percentages in the preceding table by producing a random integer, i, in the range $1 \le i \le 10$. For the tortoise, perform a "fast plod" when $1 \le i \le 5$, a "slip" when $6 \le i \le 7$ or a "slow plod" when $8 \le i \le 10$. Use a similar technique to move the hare.

Begin the race by printing

```
BANG !!!!!
AND THEY'RE OFF !!!!!
```

Then, for each tick of the clock (i.e., each repetition of a loop), print a 70-position line showing the letter **T** in the position of the tortoise and the letter **H** in the position of the hare. Occasionally, the contenders will land on the same square. In this case, the tortoise bites the hare, and your program should print **OUCH!!!** beginning at that position. All print positions other than the **T**, the **H** or the **OUCH!!!** (in case of a tie) should be blank.

After each line is printed, test for whether either animal has reached or passed square 70. If so, print the winner and terminate the simulation. If the tortoise wins, print **TORTOISE WINS!!! YAY!!!** If the hare wins, print **Hare wins. Yuch.** If both animals win on the same tick of the clock, you may want to favor the turtle (the "underdog") or you may want to print **It's a tie**. If neither animal wins, perform the loop again to simulate the next tick of the clock. When you are ready to run your program, assemble a group of fans to watch the race. You'll be amazed at how involved your audience gets!

Later in the book, we introduce a number of Java capabilities, such as graphics, images, animation, sound and multithreading. As you study those features, you might enjoy enhancing your tortoise and hare contest simulation.

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Animal	Move type	Percentage of the time	Actual move
Tortoise	Fast plod	50%	3 squares to the right
	Slip	20%	6 squares to the left
	Slow plod	30%	1 square to the right
Hare	Sleep	20%	No move at all
	Big hop	20%	9 squares to the right
	Big slip	10%	12 squares to the left
	Small hop	30%	1 square to the right
	Small slip	20%	2 squares to the left

Fig. 7.32 Rules for adjusting the positions of the tortoise and the hare.

SPECIAL SECTION: BUILDING YOUR OWN COMPUTER

In the next several problems, we take a temporary diversion away from the world of high-level language programming. We "peel open" a computer and look at its internal structure. We introduce machine-language programming and write several machine-language programs. To make this an especially valuable experience, we then build a computer (through the technique of software-based *simulation)* on which you can execute your machine-language programs!

7.42 (*Machine-Language Programming*) Let us create a computer we will call the Simpletron. As its name implies, it is a simple machine, but as we will soon see, a powerful one as well. The Simpletron runs programs written in the only language it directly understands, that is, Simpletron Machine Language or SML for short.

The Simpletron contains an *accumulator*—a "special register" in which information is put before the Simpletron uses that information in calculations or examines it in various ways. All information in the Simpletron is handled in terms of *words.* A word is a signed four-digit decimal number such as **`+3364`**, **`-1293`**, **`+0007`**, **`-0001`**, etc. The Simpletron is equipped with a 100-word memory and these words are referenced by their location numbers **`00`**, **`01`**, …, **`99`**.

Before running an SML program, we must *load* or place the program into memory. The first instruction (or statement) of every SML program is always placed in location **`00`**. The simulator will start executing at this location.

Each instruction written in SML occupies one word of the Simpletron's memory (and hence instructions are signed four-digit decimal numbers). We shall assume that the sign of an SML instruction is always plus, but the sign of a data word may be either plus or minus. Each location in the Simpletron's memory may contain either an instruction, a data value used by a program or an unused (and hence undefined) area of memory. The first two digits of each SML instruction are the *operation code* specifying the operation to be performed. SML operation codes are summarized in Fig. 7.33.

The last two digits of an SML instruction are the *operand*—the address of the memory location containing the word to which the operation applies. Let's consider several simple SML programs.

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Operation code	Meaning
Input/output operations:	
`final int READ = 10;`	Read a word from the keyboard into a specific location in memory.
`final int WRITE = 11;`	Write a word from a specific location in memory to the screen.
Load/store operations:	
`final int LOAD = 20;`	Load a word from a specific location in memory into the accumulator.
`final int STORE = 21;`	Store a word from the accumulator into a specific location in memory.
Arithmetic operations:	
`final int ADD = 30;`	Add a word from a specific location in memory to the word in the accumulator (leave result in the accumulator).
`final int SUBTRACT = 31;`	Subtract a word from a specific location in memory from the word in the accumulator (leave result in the accumulator).
`final int DIVIDE = 32;`	Divide a word from a specific location in memory into the word in the accumulator (leave result in the accumulator).
`final int MULTIPLY = 33;`	Multiply a word from a specific location in memory by the word in the accumulator (leave result in the accumulator).
Transfer of control operations:	
`final int BRANCH = 40;`	Branch to a specific location in memory.
`final int BRANCHNEG = 41;`	Branch to a specific location in memory if the accumulator is negative.
`final int BRANCHZERO = 42;`	Branch to a specific location in memory if the accumulator is 0.
`final int HALT = 43;`	Halt—the program has completed its task.

Fig. 7.33 Simpletron Machine Language (SML) operation codes .

The first SML program (Fig. 7.34) reads two numbers from the keyboard and computes and prints their sum. The instruction **`+1007`** reads the first number from the keyboard and places it into location **`07`** (which has been initialized to 0). Then, instruction **`+1008`** reads the next number into location **`08`**. The *load* instruction, **`+2007`**, puts the first number into the accumulator, and the *add* instruction, **`+3008`**, adds the second number to the number in the accumulator. *All SML arithmetic instructions leave their results in the accumulator.* The *store* instruction, **`+2109`**, places the result back into memory location **`09`** from which the *write* instruction, **`+1109`**, takes the number and prints it (as a signed four-digit decimal number). The *halt* instruction, **`+4300`**, terminates execution.

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Location	Number	Instruction
00	`+1007`	(Read A)
01	`+1008`	(Read B)
02	`+2007`	(Load A)
03	`+3008`	(Add B)
04	`+2109`	(Store C)
05	`+1109`	(Write C)
06	`+4300`	(Halt)
07	`+0000`	(Variable A)
08	`+0000`	(Variable B)
09	`+0000`	(Result C)

Fig. 7.34 SML program that reads two integers and computes their sum.

The second SML program (Fig. 7.35) reads two numbers from the keyboard and determines and prints the larger value. Note the use of the instruction `+4107` as a conditional transfer of control, much the same as Java's `if` statement.

Now write SML programs to accomplish each of the following tasks:

a) Use a sentinel-controlled loop to read 10 positive numbers. Compute and print their sum.
b) Use a counter-controlled loop to read seven numbers, some positive and some negative, and compute and print their average.
c) Read a series of numbers and determine and print the largest number. The first number read indicates how many numbers should be processed.

Location	Number	Instruction
00	`+1009`	(Read A)
01	`+1010`	(Read B)
02	`+2009`	(Load A)
03	`+3110`	(Subtract B)
04	`+4107`	(Branch negative to 07)
05	`+1109`	(Write A)
06	`+4300`	(Halt)
07	`+1110`	(Write B)
08	`+4300`	(Halt)
09	`+0000`	(Variable A)
10	`+0000`	(Variable B)

Fig. 7.35 SML program that reads two integers and determines which is larger.

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7.43 (*A Computer Simulator*) It may at first seem outrageous, but in this problem you are going to build your own computer. No, you will not be soldering components together. Rather, you will use the powerful technique of *software-based simulation* to create an object-oriented *software model* of the Simpletron. You will not be disappointed. Your Simpletron simulator will turn the computer you are using into a Simpletron, and you will actually be able to run, test and debug the SML programs you wrote in Exercise 7.42. Your Simpletron will be an event-driven applet—you will click a button to execute each SML instruction and you will be able to see the instruction "in action."

When you run your Simpletron simulator, it should begin by displaying:

```
*** Welcome to Simpletron! ***
*** Please enter your program one instruction  ***
*** (or data word) at a time into the input    ***
*** text field. I will display the location    ***
*** number and a question mark (?). You then   ***
*** type the word for that location. Press the ***
*** Done button to stop entering your program. ***
```

The program should display an **input JTextField** in which the user will type each instruction one at a time and a **Done** button for the user to click when the complete SML program has been entered. Simulate the memory of the Simpletron with a single-subscripted array **memory** that has 100 elements. Now assume that the simulator is running and let us examine the dialog as we enter the program of Fig. 7.35 (Exercise 7.42):

```
00 ? +1009
01 ? +1010
02 ? +2009
03 ? +3110
04 ? +4107
05 ? +1109
06 ? +4300
07 ? +1110
08 ? +4300
09 ? +0000
10 ? +0000
```

Your program should use a **JTextField** to display the memory location followed by a question mark. Each of the values to the right of a question mark is typed by the user into the **input JTextField**. When the **Done** button is clicked, the program should display:

```
*** Program loading completed ***
*** Program execution begins  ***
```

The SML program has now been placed (or loaded) in array **memory**. The Simpletron should provide an "**Execute next instruction**" button the user can click to execute each instruction in your SML program. Execution begins with the instruction in location **00** and, like Java, continues sequentially, unless directed to some other part of the program by a transfer of control.

Use the variable **accumulator** to represent the accumulator register. Use the variable **instructionCounter** to keep track of the location in memory that contains the instruction being performed. Use the variable **operationCode** to indicate the operation currently being performed (i.e., the left two digits of the instruction word). Use the variable **operand** to indicate the memory location on which the current instruction operates. Thus, **operand** is the rightmost two digits of the instruction currently being performed. Do not execute instructions directly from memory. Rather, transfer the next instruction to be performed from memory to a variable called **instructionRegister**. Then "pick off" the left two digits and place them in **operation-**

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Code and "pick off" the right two digits and place them in **operand**. Each of the preceding registers should have a corresponding **JTextField** in which its current value can be displayed at all times. When Simpletron begins execution, the special registers are all initialized to 0.

Now, let us "walk through" execution of the first SML instruction, **+1009** in memory location **00**. This is called an *instruction execution cycle.*

The **instructionCounter** tells us the location of the next instruction to be performed. We *fetch* the contents of that location from **memory** by using the Java statement

```
instructionRegister = memory[ instructionCounter ];
```

The operation code and the operand are extracted from the instruction register by the statements

```
operationCode = instructionRegister / 100;
operand = instructionRegister % 100;
```

Now the Simpletron must determine that the operation code is actually a *read* (versus a *write*, a *load*, etc.). A **switch** differentiates among the twelve operations of SML.

In the **switch** structure, the behavior of various SML instructions is simulated as shown in Fig. 7.36. We discuss branch instructions shortly and leave the others to the reader.

When the SML program completes execution, the name and contents of each register as well as the complete contents of memory should be displayed. Such a printout is often called a *computer dump* (and, no, a computer dump is not a place where old computers go). To help you program your dump method, a sample dump format is shown in Fig. 7.37. Note that a dump after executing a Simpletron program would show the actual values of instructions and data values at the moment execution terminated. The sample dump assumes the output will be sent to the display screen with a series of **System.out.print** and **System.out.println** method calls. However, we encourage you to experiment with a version that can be displayed on the applet using a **JTextArea** or an array of **JTextField** objects.

Let us proceed with the execution of our program's first instruction, namely the **+1009** in location **00**. As we have indicated, the **switch** statement simulates this by prompting the user to enter a value into the input dialog, reading the value, converting the value to an integer and storing it in memory location **memory[operand]**. Since your Simpletron is event driven, it waits for the user to type a value into the **input JTextField** and press the *Enter key.* The value is then read into location **09**.

At this point, simulation of the first instruction is completed. All that remains is to prepare the Simpletron to execute the next instruction. Since the instruction just performed was not a transfer of control, we need merely increment the instruction counter register as follows:

```
++instructionCounter;
```

Instruction	Description
read:	Display an input dialog with the prompt "**Enter an integer**." Convert the input value to an integer and store it in location **memory[operand]**.
load:	**accumulator = memory[operand];**
add:	**accumulator += memory[operand];**

Fig. 7.36 Behavior of several SML instructions in the Simpletron.

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```
REGISTERS:
accumulator          +0000
instructionCounter      00
instructionRegister  +0000
operationCode           00
operand                 00

MEMORY:
       0     1     2     3     4     5     6     7     8     9
 0 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
10 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
20 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
30 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
40 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
50 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
60 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
70 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
80 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
90 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000 +0000
```

Fig. 7.37 A sample dump.

This completes the simulated execution of the first instruction. When the user clicks the **Execute next instruction** button, the entire process (i.e., the instruction execution cycle) begins again with the fetch of the next instruction to be executed.

Now let us consider how the branching instructions—the transfers of control—are simulated. All we need to do is adjust the value in the instruction counter appropriately. Therefore, the unconditional branch instruction (**40**) is simulated within the **switch** as

```
instructionCounter = operand;
```

The conditional "branch if accumulator is zero" instruction is simulated as

```
if ( accumulator == 0 )
   instructionCounter = operand;
```

At this point, you should implement your Simpletron simulator and run each of the SML programs you wrote in Exercise 7.42. You may embellish SML with additional features and provide for these in your simulator.

Your simulator should check for various types of errors. During the program loading phase, for example, each number the user types into the Simpletron's **memory** must be in the range **-9999** to **+9999**. Your simulator should test that each number entered is in this range, and, if not, keep prompting the user to reenter the number until the user enters a correct number.

During the execution phase, your simulator should check for various serious errors, such as attempts to divide by zero, attempts to execute invalid operation codes, accumulator overflows (i.e., arithmetic operations resulting in values larger than **+9999** or smaller than **-9999**) and the like. Such serious errors are called *fatal errors*. When a fatal error is detected, your simulator should print an error message such as:

```
*** Attempt to divide by zero ***
*** Simpletron execution abnormally terminated ***
```

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and should print a full computer dump in the format we discussed previously. This will help the user locate the error in the program.

7.44 (*Modifications to the Simpletron Simulator*) In Exercise 7.43, you wrote a software simulation of a computer that executes programs written in Simpletron Machine Language (SML). In this exercise, we propose several modifications and enhancements to the Simpletron Simulator. In Exercise 19.26 and Exercise 19.27, we propose building a compiler that converts programs written in a high-level programming language (a variation of Basic) to Simpletron Machine Language. Some of the following modifications and enhancements may be required to execute the programs produced by the compiler:

a) Extend the Simpletron Simulator's memory to contain 1000 memory locations to enable the Simpletron to handle larger programs.
b) Allow the simulator to perform modulus calculations. This requires an additional Simpletron Machine Language instruction.
c) Allow the simulator to perform exponentiation calculations. This requires an additional Simpletron Machine Language instruction.
d) Modify the simulator to use hexadecimal values rather than integer values to represent Simpletron Machine Language instructions.
e) Modify the simulator to allow output of a newline. This requires an additional Simpletron Machine Language instruction.
f) Modify the simulator to process floating-point values in addition to integer values.
g) Modify the simulator to handle string input. [*Hint*: Each Simpletron word can be divided into two groups, each holding a two-digit integer. Each two-digit integer represents the ASCII decimal equivalent of a character. Add a machine-language instruction that will input a string and store the string beginning at a specific Simpletron memory location. The first half of the word at that location will be a count of the number of characters in the string (i.e., the length of the string). Each succeeding half-word contains one ASCII character expressed as two decimal digits. The machine-language instruction converts each character into its ASCII equivalent and assigns it to a "half-word."]
h) Modify the simulator to handle output of strings stored in the format of part g). [*Hint*: Add a machine-language instruction that will print a string beginning at a certain Simpletron memory location. The first half of the word at that location is a count of the number of characters in the string (i.e., the length of the string). Each succeeding half-word contains one ASCII character expressed as two decimal digits. The machine-language instruction checks the length and prints the string by translating each two-digit number into its equivalent character.]

7.45 The Fibonacci series

0, 1, 1, 2, 3, 5, 8, 13, 21, …

begins with the terms 0 and 1 and has the property that each succeeding term is the sum of the two preceding terms.

a) Write a *nonrecursive* method **`fibonacci( n )`** that calculates the *n*th Fibonacci number. Incorporate this method into an applet that enables the user to enter the value of **`n`**.
b) Determine the largest Fibonacci number that can be printed on your system.
c) Modify the program of part a) to use **`double`** instead of **`int`** to calculate and return Fibonacci numbers and use this modified program to repeat part b).

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Object-Based Programming

Objectives

- To understand encapsulation and data hiding.
- To understand the notions of data abstraction and abstract data types (ADTs).
- To create Java ADTs, namely, classes.
- To be able to create, use and destroy objects.
- To be able to control access to object instance variables and methods.
- To appreciate the value of object orientation.
- To understand the use of the **`this`** reference.
- To understand class variables and class methods.

My object all sublime
I shall achieve in time.
W. S. Gilbert

Is it a world to hide virtues in?
William Shakespeare, Twelfth Night

Your public servants serve you right.
Adlai Stevenson

But what, to serve our private ends,
Forbids the cheating of our friends?
Charles Churchill

This above all: to thine own self be true.
William Shakespeare, Hamlet

Have no friends not equal to yourself.
Confucius

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Outline

8.1 Introduction
8.2 Implementing a Time Abstract Data Type with a Class
8.3 Class Scope
8.4 Controlling Access to Members
8.5 Creating Packages
8.6 Initializing Class Objects: Constructors
8.7 Using Overloaded Constructors
8.8 Using Set and Get Methods
8.8.1 Executing an Applet that Uses Programmer-Defined Packages
8.9 Software Reusability
8.10 Final Instance Variables
8.11 Composition: Objects as Instance Variables of Other Classes
8.12 Package Access
8.13 Using the `this` Reference
8.14 Finalizers
8.15 Static Class Members
8.16 Data Abstraction and Encapsulation
8.16.1 Example: Queue Abstract Data Type
8.17 (Optional Case Study) Thinking About Objects: Starting to Program the Classes for the Elevator Simulation

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

8.1 Introduction

Now we investigate object orientation in Java in greater depth. Why did we defer this until now? First, the objects we will build will be composed in part of structured program pieces, so we needed to establish a basis in structured programming with control structures. Second, we wanted to study methods in depth. Third, we wanted to familiarize the reader with arrays that are Java objects.

Through our discussions of object-oriented Java programs in Chapter 2 through Chapter 7, we introduced many basic concepts (i.e., "object think") and terminology (i.e., "object speak") of object-oriented programming in Java. We also discussed our program-development methodology: We analyzed many typical problems that required a program—either a Java applet or a Java application—to be built, determined what classes from the Java API were needed to implement the program, determined what instance variables were needed, determined what methods were needed and specified how an object of our class collaborated with objects of Java API classes to accomplish the overall goals of the program.

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Let us briefly review some key concepts and terminology of object orientation. OOP *encapsulates* data (*attributes*) and methods (*behaviors*) into *objects;* the data and methods of an object are intimately tied together. Objects have the property of *information hiding.* This means that although objects might know how to communicate with one another across well-defined *interfaces,* objects normally are not allowed to know how other objects are implemented—implementation details are hidden within the objects themselves. Surely it is possible to drive a car effectively without knowing the details of how engines, transmissions and exhaust systems work internally. We will see why information hiding is so crucial to good software engineering.

In C and other *procedural programming languages,* programming tends to be *action-oriented.* In Java, programming is *object-oriented.* In C, the unit of programming is the *function* (called *methods* in Java). In Java, the unit of programming is the *class* from which objects are eventually *instantiated* (i.e., created). Functions do not disappear in Java; rather, they are encapsulated as methods with the data they process within the "walls" of classes.

C programmers concentrate on writing functions. Groups of actions that perform some task are formed into functions, and functions are grouped to form programs. Data is certainly important in C, but the view is that data exists primarily in support of the actions that functions perform. The *verbs* in a system-requirements document help the C programmer determine the set of functions that will work together to implement the system.

Java programmers concentrate on creating their own *user-defined types* called *classes.* Classes are also referred to as *programmer-defined types*. Each class contains data as well as the set of methods that manipulate the data. The data components of a class are called *instance variables* (these are called *data members* in C++). Just as an instance of a built-in type such as **`int`** is called a *variable,* an instance of a user-defined type (i.e., a class) is called an *object.* The focus of attention in Java is on objects rather than methods. The *nouns* in a system-requirements document help the Java programmer determine an initial set of classes with which to begin the design process. These classes are then used to instantiate objects that will work together to implement the system.

This chapter explains how to create and use objects, a subject called *object-based programming (OBP).* Chapter 9 introduces *inheritance* and *polymorphism*—two key technologies that enable true *object-oriented programming (OOP).* Although inheritance is not discussed in detail until Chapter 9, inheritance is part of every Java class definition.

Performance Tip 8.1

When passing an object to a method in Java, only a reference to the object is passed, not a copy of a possibly large object (as would be the case in a pass by value).

Software Engineering Observation 8.1

It is important to write programs that are understandable and easy to maintain. Change is the rule rather than the exception. Programmers should anticipate their code's being modified. As we will see, classes facilitate program modifiability.

8.2 Implementing a Time Abstract Data Type with a Class

The next example consists of two classes—**`Time1`** (Fig. 8.1) and **`TimeTest`** (Fig. 8.2). Class **`Time1`** is defined in file **`Time1.java`**. Class **`TimeTest`** is defined in a separate file called **`TimeTest.java`**. It is important to note that these classes *must* be defined in

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separate files, because they are both **public** classes. [*Note:* The output of this program appears in Fig. 8.2.]

```
1  // Fig. 8.1: Time1.java
2  // Time1 class definition maintains the time in 24-hour format.
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  public class Time1 extends Object {
8     private int hour;     // 0 - 23
9     private int minute;   // 0 - 59
10    private int second;   // 0 - 59
11
12    // Time1 constructor initializes each instance variable
13    // to zero. Ensures that each Time1 object starts in a
14    // consistent state.
15    public Time1()
16    {
17       setTime( 0, 0, 0 );
18    }
19
20    // Set a new time value using universal time. Perform
21    // validity checks on the data. Set invalid values to zero.
22    public void setTime( int h, int m, int s )
23    {
24       hour = ( ( h >= 0 && h < 24 ) ? h : 0 );
25       minute = ( ( m >= 0 && m < 60 ) ? m : 0 );
26       second = ( ( s >= 0 && s < 60 ) ? s : 0 );
27    }
28
29    // convert to String in universal-time format
30    public String toUniversalString()
31    {
32       DecimalFormat twoDigits = new DecimalFormat( "00" );
33
34       return twoDigits.format( hour ) + ":" +
35          twoDigits.format( minute ) + ":" +
36          twoDigits.format( second );
37    }
38
39    // convert to String in standard-time format
40    public String toString()
41    {
42       DecimalFormat twoDigits = new DecimalFormat( "00" );
43
44       return ( (hour == 12 || hour == 0) ? 12 : hour % 12 ) +
45          ":" + twoDigits.format( minute ) +
46          ":" + twoDigits.format( second ) +
47          ( hour < 12 ? " AM" : " PM" );
48    }
49
50 }  // end class Time1
```

Fig. 8.1 Abstract data type **Time1** implementation as a class.

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Software Engineering Observation 8.2

Class definitions that begin with keyword **`public`** *must be stored in a file that has exactly the same name as the class and ends with the* **`.java`** *file name extension.*

Common Programming Error 8.1

Defining more than one **`public`** *class in the same file is a syntax error.*

Figure 8.1 contains a simple definition for class **`Time1`**. Our **`Time1`** class definition begins with line 6, which indicates that class **`Time1`** **`extends`** class ***`Object`*** (from package **`java.lang`**). Remember that you never create a class definition "from scratch." In fact, when you create a class definition, you always use pieces of an existing class definition. Java uses *inheritance* to create new classes from existing class definitions. Keyword **`extends`** followed by class name **`Object`** indicates the class (in this case **`Time1`**) from which our new class inherits existing pieces. In this inheritance relationship, **`Object`** is called the *superclass* or *base class* and **`Time1`** is called the *subclass* or *derived class*. Using inheritance results in a new class definition that has the *attributes* (data) and *behaviors* (methods) of class **`Object`** as well as new features we add in our **`Time1`** class definition. Every class in Java is a subclass of **`Object`** (directly or indirectly). Therefore, every class inherits the 11 methods defined by class **`Object`**. One key **`Object`** method is ***`toString`***, discussed later in this section. Other methods of class **`Object`** are discussed as they are needed throughout the text. For a complete list of class Object's methods, see the online API documentation at

```
java.sun.com/j2se/1.3/docs/api/index.html
```

Software Engineering Observation 8.3

Every class defined in Java must extend another class. If a class does not explicitly use the keyword **`extends`** *in its definition, the class implicitly* **`extends`** **`Object`**.

The *body* of the class definition is delineated with left and right braces (**`{`** and **`}`**) on lines 7 and 50. Class **`Time1`** contains three integer instance variables—**`hour`**, **`minute`** and **`second`**—that represent the time in *universal-time* format (*24-hour clock* format).

Keywords ***`public`*** and ***`private`*** are *member access modifiers*. Instance variables or methods declared with member access modifier **`public`** are accessible wherever the program has a reference to a **`Time1`** object. Instance variables or methods declared with member access modifier **`private`** are accessible *only* to methods of the class in which they are defined. Every instance variable or method definition should be preceded by a member access modifier.

The three integer instance variables **`hour`**, **`minute`** and **`second`** are each declared (lines 8–10) with member access modifier **`private`**, indicating that these instance variables are accessible only to methods of the class. When a program creates (instantiates) an object of the class, such instance variables are encapsulated in the object and can be accessed only through methods of that object's class (normally through the class's **`public`** methods). Typically, instance variables are declared **`private`**, and methods are declared **`public`**. It is possible to have **`private`** methods and **`public`** data, as we will see later. The **`private`** methods are known as *utility methods* or *helper methods* because they can be called only by other methods of that class and are used to support the operation of those methods. Using **`public`** data is uncommon and is a dangerous programming practice.

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Software Engineering Observation 8.4

Methods tend to fall into a number of different categories: methods that get the values of **`private`** *instance variables; methods that set the values of* **`private`** *instance variables; methods that implement the services of the class; and methods that perform various mechanical chores for the class, such as initializing class objects, assigning class objects, and converting between classes and built-in types or between classes and other classes.*

Access methods can read or display data. Another common use for access methods is to test whether a condition is true or false—such methods are often called *predicate methods.* An example of a predicate method would be an **`isEmpty`** method for any container class—a class capable of holding many objects—such as a linked list, a stack or a queue (these data structures are discussed in depth in Chapter 19, Chapter 20 and Chapter 21). A program might test **`isEmpty`** before attempting to read another item from the container object. A program might test **`isFull`** before attempting to insert another item into the container object.

Class **`Time1`** contains the following **`public`** methods—**`Time1`** (lines 15–18), **`setTime`** (lines 22–27), **`toUniversalString`** (lines 30–37) and **`toString`** (line 40–48). These are the ***`public`*** *methods,* ***`public`*** *services* or ***`public`*** *interface* of the class. These methods are used by *clients* (i.e., portions of a program that are users of a class) of the class to manipulate the data stored in objects of the class.

The clients of a class use references to interact with an object of the class. For example, method **`paint`** in an applet is a client of class **`Graphics`**. Method **`paint`** uses a reference to a **`Graphics`** object (such as **`g`**) that it receives as an argument to draw on the applet by calling methods that are **`public`** services of class **`Graphics`** (such as **`drawString`**, **`drawLine`**, **`drawOval`** and **`drawRect`**).

Notice the method with the same name as the class (lines 15–18); it is the *constructor* method of that class. A constructor is a special method that initializes the instance variables of a class object. Java calls a class's constructor method when a program instantiates an object of that class. In this example, the constructor simply calls the class's **`setTime`** method (discussed shortly) with hour, minute and second values specified as 0.

It is common to have several constructors for a class; this is accomplished through *method overloading* (as we will see Fig. 8.6). Constructors can take arguments but cannot specify a return data type. Implicitly, the constructor returns a reference to the instantiated object. An important difference between constructors and other methods is that constructors *are not allowed to specify a return data type* (not even **`void`**). Normally, constructors are **`public`** methods of a class. Non**`public`** methods are discussed later.

Common Programming Error 8.2

Attempting to declare a return type for a constructor and/or attempting to **`return`** *a value from a constructor is a logic error. Java allows other methods of the class to have the same name as the class and to specify return types. Such methods are not constructors and will not be called when an object of the class is instantiated.*

Method **`setTime`** (lines 22–27) is a **`public`** method that receives three integer arguments and uses them to set the time. Each argument is tested in a conditional expression that determines whether the value is in range. For example, the **`hour`** value must be greater than or equal to 0 and less than 24 because we represent the time in universal time format (0–23 for the hour, 0–59 for the minute and 0–59 for the second). Any value outside this

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range is an invalid value and is set to zero—ensuring that a **Time1** object always contains valid data. This is also known as *keeping the object in a consistent state* or *maintaining the object's integrity*. In cases where invalid data is supplied to **setTime**, the program may want to indicate that an invalid time setting was attempted. We explore this possibility in the exercises.

Good Programming Practice 8.1

Always define a class so its instance variables are maintained in a consistent state.

Method **toUniversalString** (lines 30–37) takes no arguments and returns a **String**. This method produces a universal-time-format string consisting of six digits—two for the hour, two for the minute and two for the second. For example, 13:30:07 represents 1:30:07 PM. Line 32 creates an instance of class **DecimalFormat** (from package **java.text** imported at line 3) to help format the universal time. Object **twoDigits** is initialized with the *format control string* **"00"**, which indicates that the number format should consist of two digits—each **0** is a placeholder for a digit. If the number being formatted is a single digit, it is automatically preceded by a leading **0** (i.e., **8** is formatted as **08**). The **return** statement at lines 34–36 uses method **format** (which returns a formatted **String** containing the number) from object **twoDigits** to format the **hour**, **minute** and **second** values into two-digit strings. Those strings are concatenated with the **+** operator (separated by colons) and returned from method **toUniversalString**.

Method **toString** (line 40–48) takes no arguments and returns a **String**. This method produces a standard-time-format string consisting of the **hour**, **minute** and **second** values separated by colons and an AM or PM indicator, as in **1:27:06 PM**. This method uses the same **DecimalFormat** techniques as method **toUniversalString** to guarantee that the **minute** and **second** values each appear with two digits. Method **toString** is special, in that we inherited from class **Object** a **toString** method with exactly the same first line as our **toString** on line 40. The original **toString** method of class **Object** is a generic version that is used mainly as a placeholder that can be redefined by a subclass (similar to methods **init**, **start** and **paint** from class **JApplet**). Our version replaces the version we inherited to provide a **toString** method that is more appropriate for our class. This is known as *overriding* the original method definition (discussed in detail in Chapter 9).

Once the class has been defined, it can be used as a type in declarations such as

```
Time1 sunset,          // reference to object of type Time1
      timeArray[];     // reference to array of Time1 objects
```

The class name is a new type specifier. There may be many objects of a class, just as there may be many variables of a primitive data type such as **int**. The programmer can create new class types as needed; this is one of the reasons that Java is known as an *extensible language*.

The **TimeTest1** application of Fig. 8.2 uses class **Time1**. Method **main** of class **TimeTest1** declares and initializes an instance of class **Time1** called **time** in line 12. When the object is instantiated, operator **new** allocates the memory in which the **Time1** object will be stored; then **new** calls the **Time1** constructor to initialize the instance variables of the new **Time1** object. The constructor invokes method **setTime** to explicitly initialize each private instance variable to **0**. Operator **new** then returns a reference to the

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new object, and that reference is assigned to **time**. Similarly, line 32 in class **Time1** (Fig. 8.1) uses **new** to allocate the memory for a **DecimalFormat** object, then calls the **DecimalFormat** constructor with the argument **"00"** to indicate the number format control string.

Software Engineering Observation 8.5

*Every time **new** creates an object of a class, that class's constructor is called to initialize the instance variables of the new object.*

Note that class **Time1** was not **import**ed into the **TimeTest1.java** file. Actually, every class in Java is part of a *package* (like the classes from the Java API). If the programmer does not specify the package for a class, the class is automatically placed in the *default package*, which includes the compiled classes in the current directory. If a class is in the same package as the class that uses it, an **import** statement is not required. We import classes from the Java API because their **.class** files are not in the same package with each program we write. Section 8.5 illustrates how to define your own packages of classes for reuse.

```
1  // Fig. 8.2: TimeTest1.java
2  // Class TimeTest1 to exercise class Time1
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  public class TimeTest1 {
8
9     // create Time1 object and manipulate it
10    public static void main( String args[] )
11    {
12       Time1 time = new Time1();  // calls Time1 constructor
13
14       // append String version of time to String output
15       String output = "The initial universal time is: " +
16          time.toUniversalString() +
17          "\nThe initial standard time is: " +  time.toString() +
18          "\nImplicit toString() call: " + time;
19
20       // change time and append String version of time to output
21       time.setTime( 13, 27, 6 );
22       output += "\n\nUniversal time after setTime is: " +
23          time.toUniversalString() +
24          "\nStandard time after setTime is: " + time.toString();
25
26       // use invalid values to change time and append String
27       // version of time to output
28       time.setTime( 99, 99, 99 );
29       output += "\n\nAfter attempting invalid settings: " +
30          "\nUniversal time: " + time.toUniversalString() +
31          "\nStandard time: " + time.toString();
32
```

Fig. 8.2 Using an object of class **Time1** in a program (part 1 of 2).

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```
33          JOptionPane.showMessageDialog( null, output,
34             "Testing Class Time1",
35             JOptionPane.INFORMATION_MESSAGE );
36
37          System.exit( 0 );
38       }
39
40    }  // end class TimeTest1
```

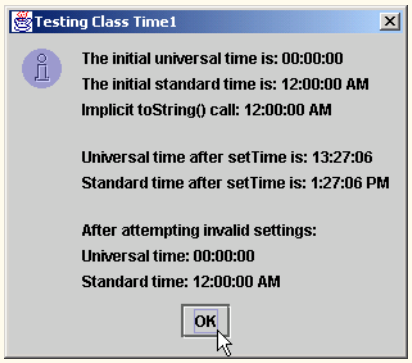

Fig. 8.2 Using an object of class **Time1** in a program (part 2 of 2).

The statement at lines 15–18 defines a **String** reference **output**, which stores the string containing the results that will be displayed in a message box. Initially, the program assigns to **output** the time in universal-time format (by sending message **toUniversalString** to the object to which **time** refers) and standard-time format (by sending message **toString** to the object to which **time** refers) to confirm that the data were initialized properly. Note that line 18 uses a special string concatenation feature of Java. Concatenating a **String** with any object results in an implicit call to the object's **toString** method to convert the object to a **String**; then the **String**s are concatenated. Lines 17–18 illustrate that you can call **toString** both explicitly and implicitly in a **String** concatenation operation.

Line 21 sends the **setTime** message to the object to which **time** refers to change the time. Then lines 22–24 append the time to **output** again in both formats to confirm that the time was set correctly.

To illustrate that method **setTime** validates the values passed to it, line 28 calls method **setTime** and attempts to set the instance variables to invalid values. Then lines 29–31 append the time to **output** again in both formats to confirm that **setTime** validated the data. Lines 33–35 display a message box with the results of our program. Notice in the last two lines of the output window that the time is set to midnight—the default value of a **Time1** object.

Now that we have seen our first non-applet, non-application class, let us consider several issues of class design.

Again, note that the instance variables **hour**, **minute** and **second** are each declared **private**. Instance variables declared **private** are not accessible outside the class in which they are defined. The philosophy here is that the actual data representation used within the class is of no concern to the class's clients. For example, it would be perfectly

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reasonable for the class to represent the time internally as the number of seconds since midnight. Clients could use the same **`public`** methods and get the same results without being aware of this. In this sense, implementation of a class is said to be *hidden* from its clients. Exercise 8.18 asks you to make precisely this modification to the **`Time1`** class of Figure 8.1 and show that there is no change visible to the clients of the class.

Software Engineering Observation 8.6

Information hiding promotes program modifiability and simplifies the client's perception of a class. The client should not require knowledge of a class's implementation (known as implementation knowledge) to be able to reuse a class.

Software Engineering Observation 8.7

Clients of a class can (and should) use the class without knowing the internal details of how the class is implemented. If the class implementation is changed (to improve performance, for example), the class clients' source code need not change, provided that the class's interface remains constant. This makes it much easier to modify systems.

In this program, the **`Time1`** constructor simply initializes the instance variables to 0 (i.e., the universal time equivalent of 12 AM). This ensures that the object is created in a *consistent state* (i.e., all instance variable values are valid). Invalid values cannot be stored in the instance variables of a **`Time1`** object, because the constructor is automatically called when the **`Time1`** object is created and subsequent attempts by a client to modify the instance variables are scrutinized by the method **`setTime`**.

Instance variables can be initialized where they are declared in the class body, by the class's constructor, or they can be assigned values by "set" methods. (Remember, instance variables that are not initialized explicitly receive default values (primitive numeric variables are set to 0, **`boolean`**s are set to **`false`** and references are set to **`null`**).

Good Programming Practice 8.2

Initialize instance variables of a class in that class's constructor.

Every class may include a *finalizer* method called **`finalize`** that does "termination housekeeping" on each class object before the memory for the object is garbage collected by the system. We will discuss garbage collection and finalizers in detail in Section 8.14 and Section 8.15.

It is interesting that the **`toUniversalString`** and **`toString`** methods take no arguments. This is because these methods implicitly know that they are to manipulate the instance variables of the particular **`Time1`** object for which they are invoked. This makes method calls more concise than conventional function calls in procedural programming. It also reduces the likelihood of passing the wrong arguments, the wrong types of arguments and/or the wrong number of arguments, as often happens in C function calls.

Software Engineering Observation 8.8

Using an object-oriented programming approach can often simplify method calls by reducing the number of parameters to be passed. This benefit of object-oriented programming derives from the fact that encapsulation of instance variables and methods within an object gives the methods the right to access the instance variables.

Classes simplify programming because the client (or user of the class object) need only be concerned with the **`public`** operations encapsulated in the object. Such operations are

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usually designed to be client oriented rather than implementation oriented. Clients need not be concerned with a class's implementation. Interfaces do change, but less frequently than implementations. When an implementation changes, implementation-dependent code must change accordingly. By hiding the implementation, we eliminate the possibility of other program parts becoming dependent on the details of the class implementation.

Often, classes do not have to be created "from scratch." Rather, they can be *derived* from other classes that provide operations the new classes can use, or classes can include objects of other classes as members. Such *software reuse* can greatly enhance programmer productivity. Deriving new classes from existing classes is called *inheritance*—a distinguishing feature between object-based programming and object-oriented programming—and is discussed in detail in Chapter 9. Including class objects as members of other classes is called *composition* or *aggregation* and is discussed later in this chapter.

8.3 Class Scope

A class's instance variables and methods belong to that *class's scope*. Within a class's scope, class members are accessible to all of that class's methods and can be referenced simply by name. Outside a class's scope, class members cannot be referenced directly by name. Those class members (such as **`public`** members) that are visible can be accessed only through a "handle" (i.e., primitive data type members can be referred to by *objectReferenceName*`.`*primitiveVariableName* and object members can be referenced by *objectReferenceName*`.`*objectMemberName*). For example, a program can determine the number of elements in an array object by accessing the array's **`public`** member **`length`** as in *arrayName*`.length`.

Variables defined in a method are known only to that method (i.e., they are local variables to that method). Such variables are said to have block scope. If a method defines a variable with the same name as a variable with class scope (i.e., an instance variable), the class-scope variable is hidden by the method-scope variable in the method scope. A hidden instance variable can be accessed in the method by preceding its name with the keyword **`this`** and the dot operator, as in **`this.`***variableName*. Keyword **`this`** is discussed Section 8.13.

8.4 Controlling Access to Members

The member access modifiers **`public`** and **`private`** control access to a class's instance variables and methods. (In Chapter 9, we will introduce the additional access modifier **`protected`**.) As we stated previously, the primary purpose of **`public`** methods is to present to the class's clients a view of the *services* the class provides (i.e., the public interface of the class). Clients of the class need not be concerned with how the class accomplishes its tasks. For this reason, the **`private`** instance variables and **`private`** methods of a class (i.e., the class's implementation details) are not accessible to the clients of a class. Restricting access to class members via keyword **`private`** is called *encapsulation*.

Common Programming Error 8.3

An attempt by a method that is not a member of a particular class to access a **`private`** *member of that class is a syntax error.*

Figure 8.3 demonstrates that **`private`** class members are not accessible by name outside the class. Line 10 attempts to access directly the **`private`** instance variable **`hour`** of

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the **Time1** object to which **time** refers. When this program is compiled, the compiler generates an error stating that the **private** member **hour** is not accessible. [Note: This program assumes that the **Time1** class from Figure 8.1 is used.]

Good Programming Practice 8.3

*Our preference is to list the **private** instance variables of a class first, so that, as you read the code, you see the names and types of the instance variables before they are used in the methods of the class.*

Software Engineering Observation 8.9

*Keep all the instance variables of a class **private**. When necessary, provide **public** methods to set the values of **private** instance variables and to get the values of **private** instance variables. This architecture helps hide the implementation of a class from its clients, which reduces bugs and improves program modifiability.*

Access to **private** data should be controlled carefully by the class's methods. For example, to allow clients to read the value of **private** data, the class can provide a *"get" method* (also called an *accessor method*). To enable clients to modify **private** data, the class can provide a *"set" method* (also called a *mutator method*). Such modification would seem to violate the notion of **private** data, but a *set* method can provide data validation capabilities (such as range checking) to ensure that the value is set properly. A *set* method can also translate between the form of the data used in the interface and the form used in the implementation. A *get* method need not expose the data in "raw" format; rather, the *get* method can edit the data and limit the view of the data the client will see.

Software Engineering Observation 8.10

*Class designers use **private** data and **public** methods to enforce the notion of information hiding and the principle of least privilege. If the client of a class needs access to data in the class, provide that access through **public** methods of the class. By doing so, the programmer of the class controls how the class's data is manipulated (e.g., data validity checking can prevent invalid data from being stored in an object). This is the principle of data encapsulation.*

```
1  // Fig. 8.3: TimeTest2.java
2  // Demonstrate errors resulting from attempts
3  // to access private members of class Time1.
4  public class TimeTest2 {
5
6     public static void main( String args[] )
7     {
8        Time1 time = new Time1();
9
10       time.hour = 7;
11    }
12 }
```

```
TimeTest2.java:10: hour has private access in Time1
      time.hour = 7;
          ^
1 error
```

Fig. 8.3 Erroneous attempt to access private members of class **Time1**.

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Software Engineering Observation 8.11

The class designer need not provide set *and/or* get *methods for each* **`private`** *data member; these capabilities should be provided only when it makes sense and after careful thought by the class designer.*

Testing and Debugging Tip 8.1

Making the instance variables of a class **`private`** *and the methods of the class* **`public`** *facilitates debugging because problems with data manipulations are localized to the class's methods.*

8.5 Creating Packages

As we have seen in almost every example in the text, classes and *interfaces* (discussed in Chapter 9) from preexisting libraries, such as the Java API, can be imported into a Java program. Each class and interface in the Java API belongs to a specific package that contains a group of related classes and interfaces. As applications become more complex, packages help programmers manage the complexity of application components. Packages also facilitate software reuse by enabling programs to import classes from other packages (as we have done in almost every example to this point). Another benefit of packages is that they provide a convention for *unique class names*. With hundreds of thousands of Java programmers around the world, there is a good chance that the names you choose for classes will conflict with the names that other programmers choose for their classes. This section introduces how to create your own packages and discusses the standard distribution mechanism for packages.

The application of Fig. 8.4 and Fig. 8.5 illustrates how to create your own package and use a class from that package in a program. The steps for creating a reusable class are:

1. Define a **`public`** class. If the class is not **`public`**, it can be used only by other classes in the same package.
2. Choose a package name, and add a **`package`** statement to the source code file for the reusable class definition. [Note: There can be only one **`package`** statement in a Java source code file.]
3. Compile the class so it is placed in the appropriate package directory structure.
4. Import the reusable class into a program, and use the class.

Common Programming Error 8.4

A syntax error occurs if any code appears in a Java file before the **`package`** *statement (if there is one) in the file.*

We chose to demonstrate *Step 1* by modifying the **`public`** class **`Time1`** defined in Fig. 8.1. The new version is shown in Fig. 8.4. No modifications have been made to the implementation of the class, so we will not discuss the implementation details of the class again here.

To satisfy *Step 2*, we added a **`package`** statement at the beginning of the file. Line 3 uses a **`package`** *statement* to define a **`package`** named **`com.deitel.jhtp4.ch08`**. Placing a **`package`** statement at the beginning of a Java source file indicates that the class defined in the file is part of the specified package. The only types of statements in Java that can appear outside the braces of a class definition are **`package`** statements and **`import`** statements.

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```
1  // Fig. 8.4: Time1.java
2  // Time1 class definition in a package
3  package com.deitel.jhtp4.ch08;
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  public class Time1 extends Object {
9     private int hour;     // 0 - 23
10    private int minute;   // 0 - 59
11    private int second;   // 0 - 59
12
13    // Time1 constructor initializes each instance variable
14    // to zero. Ensures that each Time1 object starts in a
15    // consistent state.
16    public Time1()
17    {
18       setTime( 0, 0, 0 );
19    }
20
21    // Set a new time value using universal time. Perform
22    // validity checks on the data. Set invalid values to zero.
23    public void setTime( int h, int m, int s )
24    {
25       hour = ( ( h >= 0 && h < 24 ) ? h : 0 );
26       minute = ( ( m >= 0 && m < 60 ) ? m : 0 );
27       second = ( ( s >= 0 && s < 60 ) ? s : 0 );
28    }
29
30    // convert to String in universal-time format
31    public String toUniversalString()
32    {
33       DecimalFormat twoDigits = new DecimalFormat( "00" );
34
35       return twoDigits.format( hour ) + ":" +
36          twoDigits.format( minute ) + ":" +
37          twoDigits.format( second );
38    }
39
40    // convert to String in standard-time format
41    public String toString()
42    {
43       DecimalFormat twoDigits = new DecimalFormat( "00" );
44
45       return ( (hour == 12 || hour == 0) ? 12 : hour % 12 ) +
46          ":" + twoDigits.format( minute ) +
47          ":" + twoDigits.format( second ) +
48          ( hour < 12 ? " AM" : " PM" );
49    }
50
51 }  // end class Time1
```

Fig. 8.4 Placing Class **Time1** in a package for reuse.

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Software Engineering Observation 8.12

A Java source code file has the following order: a **`package`** *statement (if any), zero or more* **`import`** *statements, then class definitions. Only one of the class definitions in a particular file can be* **`public`***. Other classes in the file are also placed in the package, but are reusable only from other classes in that package—they cannot be imported into classes in another package. They are in the package to support the reusable class in the file.*

In an effort to provide unique names for every package, Sun Microsystems specifies a convention for package naming that all Java programmers should follow. Every package name should start with your Internet domain name in reverse order. For example, our Internet domain name is **`deitel.com`**, so we began our package name with **`com.deitel`**. If your domain name is *yourcollege*`.edu`, the package name you would use is **`edu.`***yourcollege*. After the domain name is reversed, you can choose any other names you want for your package. If you are part of a company with many divisions or a university with many schools, you may want to use the name of your division or school as the next name in the package. We chose to use **`jhtp4`** as the next name in our package name to indicate that this class is from *Java How to Program: Fourth Edition*. The last name in our package name specifies that this package is for Chapter 8 (**`ch08`**). [Note: We use our own packages several times throughout the book. You can determine the chapter in which one of our reusable classes is defined by looking at the last part of the package name in the **`import`** statement. This appears before the name of the class being imported or before the **`*`** if a particular class is not specified.]

Step 3 is to compile the class so it is stored in the appropriate package. When a Java file containing a **`package`** statement is compiled, the resulting **`.class`** file is placed in the directory structure specified by the **`package`** statement. The preceding **`package`** statement indicates that class **`Time1`** should be placed in the directory **`ch08`**. The other names—**`com`**, **`deitel`** and **`jhtp4`**—are also directories. The directory names in the **`package`** statement specify the exact location of the classes in the package. If these directories do not exist before the class is compiled, the compiler creates them.

When compiling a class in a package, there is an extra option (**`-d`**) that must be passed to the **`javac`** compiler. This option specifies where to create (or locate) the directories in the **`package`** statement. For example, we used the compilation command

```
javac -d . Time1.java
```

to specify that the first directory specified in our package name should be placed in the current directory. The **`.`** after **`-d`** in the preceding command represents the current directory on the Windows, UNIX and Linux operating systems (and several others as well). After executing the compilation command, the current directory contains a directory called **`com`**, **`com`** contains a directory called **`deitel`**, **`deitel`** contains a directory called **`jhtp4`** and **`jhtp4`** contains a directory called **`ch08`**. In the **`ch08`** directory, you can find the file **`Time1.class`**.

The **`package`** directory names become part of the class name when the class is compiled. The class name in this example is actually **`com.deitel.jhtp4.ch08.Time1`** after the class is compiled. You can use this *fully qualified* name in your programs or you can **`import`** the class and use its short name (**`Time1`**) in the program. If another package also contains a **`Time1`** class, the fully qualified class names can be used to distinguish between the classes in the program and prevent a naming conflict (also called a name collision).

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Once the class is compiled and stored in its package, the class can be imported into programs (*Step 4*). The **TimeTest3** application of Fig. 8.5, line 8 specifies that class **Time1** should be **import**ed for use in class **TimeTest3**.

At compile time for class **TimeTest3**, **javac** must locate **.class** file for **Time1**, so **javac** can ensure that class **TimeTest3** uses class **Time1** correctly. The compiler follows a specific search order to locate the classes it needs. It begins by searching the standard Java classes that are bundled with the J2SDK. Then it searches for *extension classes*. Java 2 provides an *extensions mechanism* that enables new packages to be added to Java for development and execution purposes. [*Note*: The extensions mechanism is beyond the scope of this book. For more information, visit **java.sun.com/j2se/1.3/docs/guide/extensions**.] If the class is not found in the standard Java classes or in the extension classes, the complier searches the *class path*. By default, the class path consists only of the current directory. However, the class path can be modified by:

```
1  // Fig. 8.5: TimeTest3.java
2  // Class TimeTest3 to use imported class Time1
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  // Deitel packages
8  import com.deitel.jhtp4.ch08.Time1;  // import Time1 class
9
10 public class TimeTest3 {
11
12    // create an object of class Time1 and manipulate it
13    public static void main( String args[] )
14    {
15       Time1 time = new Time1();     // create Time1 object
16
17       time.setTime( 13, 27, 06 );  // set new time
18       String output =
19          "Universal time is: " + time.toUniversalString() +
20          "\nStandard time is: " + time.toString();
21
22       JOptionPane.showMessageDialog( null, output,
23          "Packaging Class Time1 for Reuse",
24          JOptionPane.INFORMATION_MESSAGE );
25
26       System.exit( 0 );
27    }
28
29 }  // end class TimeTest3
```

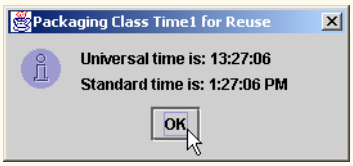

Fig. 8.5 Using programmer-defined class **Time1** in a package.

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1. providing the **-classpath** option to the **javac** compiler, or
2. setting the **CLASSPATH** environment variable (a special variable that you define and the operating system maintains so that applications can search for classes in the specified locations).

In each case, the class path consists of a list of directories and/or *archive files* separated by semicolons (**;**). Archive files are individual files that contain directories of other files, typically in compressed format. For example, the standard classes of Java are contained in the archive file **rt.jar** that is installed with the J2SDK. Archive files normally end with the **.jar** or **.zip** file name extensions. The directories and archive files specified in the class path contain the classes you wish to make available to the Java compiler. For more information on the class path, visit **java.sun.com/j2se/1.3/docs/tooldocs/win32/classpath.html** for Windows or **java.sun.com/j2se/1.3/docs/tooldocs/solaris/classpath.html** for Solaris/Linux. [*Note*: We discuss archive files in more detail in Section 8.8.]

Common Programming Error 8.5

*Specifying an explicit class path eliminates the current directory from the class path. This prevents classes in the current directory from loading properly. If classes must be loaded from the current directory, include the current directory (**.**) in the explicit class path.*

Software Engineering Observation 8.13

*In general, it is a better practice to use the **-classpath** option of the compiler, rather than the **CLASSPATH** environment variable, to specify the class path for a program. This enables each application to have its own class path.*

Testing and Debugging Tip 8.2

*Specifying the class path with the **CLASSPATH** environment variable can cause subtle and difficult-to-locate errors in programs that use different versions of the same packages.*

For the example of Fig. 8.4 and Fig. 8.5, we did not specify an explicit class path. Thus, to locate the classes in the **com.deitel.jhtp4.ch08** package from this example, the compiler looks in the current directory for the first name in the package—**com**. Next, the compiler navigates the directory structure. Directory **com** contains the subdirectory **deitel**. Directory **deitel** contains the subdirectory **jhtp4**. Finally, directory **jhtp4** contains subdirectory **ch08**. In the **ch08** directory is the file **Time1.class**, which is loaded by the compiler to ensure that the class is used properly in our program.

Locating the classes to execute the program is similar to locating the classes to compile the program. Like the compiler, the **java** interpreter searches the standard classes and extension classes first, then searches the class path (the current directory by default). The class path for the interpreter can be specified explicitly by using either of the techniques discussed for the compiler. As with the compiler, it is better to specify an individual program's class path via command-line options to the interpreter. You can specify the class path to the **java** interpreter via the **-classpath** or **-cp** command line options followed by a list of directories and/or archive files separated by semicolons (**;**).

8.6 Initializing Class Objects: Constructors

When an object is created, its members can be initialized by a *constructor* method. A constructor is a method with the same name as the class (including case sensitivity). The pro-

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grammer of a class can define the class's constructor, which is invoked each time the program instantiates an object of that class. Instance variables can be initialized implicitly to their default values (**0** for primitive numeric types, **false** for **boolean**s and **null** for references), they can be initialized in a constructor of the class or their values can be set later after the object is created. Constructors cannot specify return types or return values. A class can contain overloaded constructors to provide a variety of means for initializing objects of that class.

When a program instantiates an object of a class, the program can supply *initializers* in parentheses to the right of the class name. These initializers are passed as arguments to the class's constructor. This technique is demonstrated in the example of Section 8.7. We have also seen this technique several times previously as we created new objects of classes like **DecimalFormat**, **JLabel**, **JTextField**, **JTextArea** and **JButton**. For each of these classes, we have seen statements of the form

```
ref = new ClassName( arguments );
```

where **ref** is a reference of the appropriate data type, **new** indicates that a new object is being created, *ClassName* indicates the type of the new object and *arguments* specifies the values used by the class's constructor to initialize the object.

If no constructors are defined for a class, the compiler creates a *default constructor* that takes no arguments (also called a *no-argument constructor*). The default constructor for a class calls the default constructor for its superclass (the class it extends), then proceeds to initialize the instance variables in the manner we discussed previously. If the class that this class extends does not have a default constructor, the compiler issues an error message. It is also possible for the programmer to provide a no-argument constructor, as we showed in class **Time1** and will see in the next example. If any constructors are defined for a class by the programmer, Java will not create a default constructor for the class.

Good Programming Practice 8.4

When appropriate (almost always), provide a constructor to ensure that every object is properly initialized with meaningful values.

Common Programming Error 8.6

If constructors are provided for a class, but none of the **public** *constructors are no-argument constructors, and an attempt is made to call a no-argument constructor to initialize an object of the class, a syntax error occurs. A constructor can be called with no arguments only if there are no constructors for the class (the default constructor is called) or if there is a no-argument constructor.*

8.7 Using Overloaded Constructors

Methods of a class can be *overloaded* (i.e., several methods in a class may have exactly the same name as defined in Chapter 6, Methods). To overload a method of a class, simply provide a separate method definition with the same name for each version of the method. Remember that overloaded methods *must* have different parameter lists.

Common Programming Error 8.7

Attempting to overload a method of a class with another method that has the exact same signature (name and parameters) is a syntax error.

The **Time1** constructor in Fig. 8.1 initialized **hour**, **minute** and **second** to **0** (i.e., 12 midnight in universal time) with a call to the class's **setTime** method. Figure 8.6

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overloads the constructor method to provide a convenient variety of ways to initialize objects of the new class **Time2**. The constructors guarantee that every object begins its existence in a consistent state. In this program, each constructor calls method **setTime** with the values passed to the constructor, to ensure that the value supplied for **hour** is in the range 0 to 23 and that the values for **minute** and **second** are each in the range 0 to 59. If a value is out of range, it is set to zero by **setTime** (once again ensuring that each instance variable remains in a consistent state). The appropriate constructor is invoked by matching the number, types and order of the arguments specified in the constructor call with the number, types and order of the parameters specified in each constructor definition. The matching constructor is called automatically. Figure 8.7 uses class **Time2** to demonstrate its constructors.

```
1  // Fig. 8.6: Time2.java
2  // Time2 class definition with overloaded constructors.
3  package com.deitel.jhtp4.ch08;
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  public class Time2 extends Object {
9     private int hour;     // 0 - 23
10    private int minute;   // 0 - 59
11    private int second;   // 0 - 59
12
13    // Time2 constructor initializes each instance variable
14    // to zero. Ensures that Time object starts in a
15    // consistent state.
16    public Time2()
17    {
18       setTime( 0, 0, 0 );
19    }
20
21    // Time2 constructor: hour supplied, minute and second
22    // defaulted to 0
23    public Time2( int h )
24    {
25       setTime( h, 0, 0 );
26    }
27
28    // Time2 constructor: hour and minute supplied, second
29    // defaulted to 0
30    public Time2( int h, int m )
31    {
32       setTime( h, m, 0 );
33    }
34
35    // Time2 constructor: hour, minute and second supplied
36    public Time2( int h, int m, int s )
37    {
38       setTime( h, m, s );
39    }
```

Fig. 8.6 Class **Time2** with overloaded constructors (part 1 of 2).

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```
40
41     // Time2 constructor: another Time2 object supplied
42     public Time2( Time2 time )
43     {
44        setTime( time.hour, time.minute, time.second );
45     }
46
47     // Set a new time value using universal time. Perform
48     // validity checks on data. Set invalid values to zero.
49     public void setTime( int h, int m, int s )
50     {
51        hour = ( ( h >= 0 && h < 24 ) ? h : 0 );
52        minute = ( ( m >= 0 && m < 60 ) ? m : 0 );
53        second = ( ( s >= 0 && s < 60 ) ? s : 0 );
54     }
55
56     // convert to String in universal-time format
57     public String toUniversalString()
58     {
59        DecimalFormat twoDigits = new DecimalFormat( "00" );
60
61        return twoDigits.format( hour ) + ":" +
62           twoDigits.format( minute ) + ":" +
63           twoDigits.format( second );
64     }
65
66     // convert to String in standard-time format
67     public String toString()
68     {
69        DecimalFormat twoDigits = new DecimalFormat( "00" );
70
71        return ( (hour == 12 || hour == 0) ? 12 : hour % 12 ) +
72           ":" + twoDigits.format( minute ) +
73           ":" + twoDigits.format( second ) +
74           ( hour < 12 ? " AM" : " PM" );
75     }
76
77  }  // end class Time2
```

Fig. 8.6 Class **Time2** with overloaded constructors (part 2 of 2).

Most of the code in class **Time2** is identical to that in class **Time1**, so we concentrate on only the new features here (i.e., the constructors). Lines 16–19 define the no-argument (default) constructor. Lines 23–26 define a **Time2** constructor that receives a single **int** argument representing the **hour**. Lines 30–33 defines a **Time2** constructor that receives two **int** arguments representing the **hour** and **minute**. Lines 36–39 define a **Time2** constructor that receives three **int** arguments representing the **hour**, **minute** and **second**. Lines 42–45 define a **Time2** constructor that receives a **Time2** reference to another **Time2** object. In this case, the values from the **Time2** argument are used to initialize the **hour**, **minute** and **second**. Notice that none of the constructors specifies a return data type (remember, this is not allowed for constructors). Also, notice that all the constructors receive different numbers of arguments and/or different types of arguments. Even though only two

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of the constructors receive values for the **hour**, **minute** and **second**, all the constructors call **setTime** with values for **hour**, **minute** and **second** and substitute zeros for the missing values to satisfy **setTime**'s requirement of three arguments.

Notice in particular the constructor at lines 42–45, which uses the **hour**, **minute** and **second** values of its argument **time** to initialize the new **Time2** object. Even though we know that **hour**, **minute** and **second** are declared as **private** variables of class **Time2**, we are able to access these values directly by using the expressions **time.hour**, **time.minute** and **time.second**. This is due to a special relationship between objects of the same class. When one object of a class has a reference to another object of the same class, the first object can access *all* the second object's data and methods.

Class **TimeTest4** (Fig. 8.7) creates six **Time2** objects (lines 17–22) to demonstrate how to invoke the different constructors of the class. Line 17 shows that the no-argument constructor is invoked by placing an empty set of parentheses after the class name when allocating a **Time2** object with **new**. Lines 18–22 of the program demonstrate passing arguments to the **Time2** constructors. Remember that the appropriate constructor is invoked by matching the number, types and order of the arguments specified in the constructor call with the number, types and order of the parameters specified in each method definition. So, line 18 invokes the constructor at line 23 of Fig. 8.6. Line 19 invokes the constructor at line 30 of Fig. 8.6. Lines 20–21 invoke the constructor at line 36 of Fig. 8.6. Line 22 invokes the constructor at line 42 of Fig. 8.6.

Note that each **Time2** constructor in Fig. 8.6 could be written to include a copy of the appropriate statements from method **setTime**. This could be slightly more efficient, because the extra call to **setTime** is eliminated. However, consider changing the representation of the time from three **int** values (requiring 12 bytes of memory) to a single **int** value representing the total number of seconds that have elapsed in the day (requiring 4 bytes of memory). Coding the **Time2** constructors and method **setTime** identically makes such a change in this class definition more difficult. If the implementation of method **setTime** changes, the implementation of the **Time2** constructors would need to change accordingly. Having the **Time2** constructors call **setTime** directly requires any changes to the implementation of **setTime** to be made only once. This reduces the likelihood of a programming error when altering the implementation.

Software Engineering Observation 8.14

If a method of a class already provides all or part of the functionality required by a constructor (or other method) of the class, call that method from the constructor (or other method). This simplifies the maintenance of the code and reduces the likelihood of an error if the implementation of the code is modified. It is also an effective example of reuse.

```
1  // Fig. 8.7: TimeTest4.java
2  // Using overloaded constructors
3
4  // Java extension packages
5  import javax.swing.*;
6
```

Fig. 8.7 Using overloaded constructors to initialize objects of class **Time2** (part 1 of 3).

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```
// Deitel packages
import com.deitel.jhtp4.ch08.Time2;

public class TimeTest4 {

   // test constructors of class Time2
   public static void main( String args[] )
   {
      Time2 t1, t2, t3, t4, t5, t6;

      t1 = new Time2();                 // 00:00:00
      t2 = new Time2( 2 );              // 02:00:00
      t3 = new Time2( 21, 34 );         // 21:34:00
      t4 = new Time2( 12, 25, 42 );     // 12:25:42
      t5 = new Time2( 27, 74, 99 );     // 00:00:00
      t6 = new Time2( t4 );             // 12:25:42

      String output = "Constructed with: " +
         "\nt1: all arguments defaulted" +
         "\n      " + t1.toUniversalString() +
         "\n      " + t1.toString();

      output += "\nt2: hour specified; minute and " +
         "second defaulted" +
         "\n      " + t2.toUniversalString() +
         "\n      " + t2.toString();

      output += "\nt3: hour and minute specified; " +
         "second defaulted" +
         "\n      " + t3.toUniversalString() +
         "\n      " + t3.toString();

      output += "\nt4: hour, minute, and second specified" +
         "\n      " + t4.toUniversalString() +
         "\n      " + t4.toString();

      output += "\nt5: all invalid values specified" +
         "\n      " + t5.toUniversalString() +
         "\n      " + t5.toString();

      output += "\nt6: Time2 object t4 specified" +
         "\n      " + t6.toUniversalString() +
         "\n      " + t6.toString();

      JOptionPane.showMessageDialog( null, output,
         "Demonstrating Overloaded Constructors",
         JOptionPane.INFORMATION_MESSAGE );

      System.exit( 0 );
   }

}  // end class TimeTest4
```

Fig. 8.7 Using overloaded constructors to initialize objects of class **Time2** (part 2 of 3).

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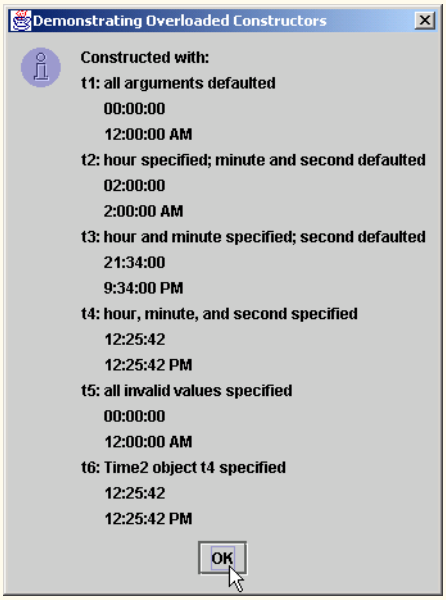

Fig. 8.7 Using overloaded constructors to initialize objects of class **`Time2`** (part 3 of 3).

8.8 Using *Set* and *Get* Methods

Private instance variables can be manipulated only by methods of the class. A typical manipulation might be the adjustment of a customer's bank balance (e.g., a **`private`** instance variable of a class **`BankAccount`**) by a method **`computeInterest`**.

Classes often provide **`public`** methods to allow clients of the class to *set* (i.e., assign values to) or *get* (i.e., obtain the values of) **`private`** instance variables. These methods need not be called *set* and *get*, but they often are.

As a naming example, a method that sets instance variable **`interestRate`** would typically be named **`setInterestRate`** and a method that gets the **`interestRate`** would typically be called **`getInterestRate`**. *Get* methods are also commonly called *accessor methods* or *query methods*. *Set* methods are also commonly called *mutator methods* (because they typically change a value).

It would seem that providing *set* and *get* capabilities is essentially the same as making the instance variables **`public`**. This is another subtlety of Java that makes the language so desirable for software engineering. If an instance variable is **`public`**, the instance variable can be read or written at will by any method in the program. If an instance variable is **`private`**, a **`public`** *get* method certainly seems to allow other methods to read the data at will but the *get* method controls the formatting and display of the data. A **`public`** *set* method can—and most likely will—carefully scrutinize attempts to modify the instance variable's value. This ensures that the new value is appropriate for that data item. For example, an attempt to *set* the day of the month for a date to 37 would be rejected, an attempt to *set* a person's weight to a negative value would be rejected, and so on. So,

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although *set* and *get* methods could provide access to **private** data, the access is restricted by the programmer's implementation of the methods.

The benefits of data integrity are not automatic simply because instance variables are made **private**—the programmer must provide validity checking. Java provides the framework in which programmers can design better programs in a convenient manner.

Software Engineering Observation 8.15

Methods that set the values of **private** *data should verify that the intended new values are proper; if they are not, the* set *methods should place the* **private** *instance variables into an appropriate consistent state.*

A class's *set* methods can return values indicating that attempts were made to assign invalid data to objects of the class. This enables clients of the class to test the return values of *set* methods to determine whether the objects they are manipulating are valid and to take appropriate action if the objects are not valid. In Chapter 14, Exception Handling, we illustrate a more robust way in which clients of a class can be notified if an object is not valid.

Good Programming Practice 8.5

Every method that modifies the private instance variables of an object should ensure that the data remains in a consistent state.

The applet of Fig. 8.8 (class **Time3**) and Fig. 8.9 (class **TimeTest5**) enhances our **Time** class (now called **Time3**) to include *get* and *set* methods for the **hour**, **minute** and **second private** instance variables. The *set* methods strictly control the setting of the instance variables to valid values. Attempts to set any instance variable to an incorrect value cause the instance variable to be set to zero (thus leaving the instance variable in a consistent state). Each *get* method simply returns the appropriate instance variable's value. This applet introduces enhanced GUI event handling techniques as we move toward defining our first full-fledged windowed application. After discussing the code, we introduce how to set up an applet to use classes in programmer-defined packages.

```
1  // Fig. 8.8: Time3.java
2  // Time3 class definition with set and get methods
3  package com.deitel.jhtp4.ch08;
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  public class Time3 extends Object {
9     private int hour;     // 0 - 23
10    private int minute;   // 0 - 59
11    private int second;   // 0 - 59
12
13    // Time3 constructor initializes each instance variable
14    // to zero. Ensures that Time object starts in a
15    // consistent state.
16    public Time3()
17    {
18       setTime( 0, 0, 0 );
19    }
```

Fig. 8.8 Class **Time3** with *set* and *get* methods (part 1 of 3).

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```
20
21    // Time3 constructor: hour supplied, minute and second
22    // defaulted to 0
23    public Time3( int h )
24    {
25       setTime( h, 0, 0 );
26    }
27
28    // Time3 constructor: hour and minute supplied, second
29    // defaulted to 0
30    public Time3( int h, int m )
31    {
32       setTime( h, m, 0 );
33    }
34
35    // Time3 constructor: hour, minute and second supplied
36    public Time3( int h, int m, int s )
37    {
38       setTime( h, m, s );
39    }
40
41    // Time3 constructor: another Time3 object supplied
42    public Time3( Time3 time )
43    {
44       setTime( time.getHour(), time.getMinute(),
45          time.getSecond() );
46    }
47
48    // Set Methods
49    // Set a new time value using universal time. Perform
50    // validity checks on data. Set invalid values to zero.
51    public void setTime( int h, int m, int s )
52    {
53       setHour( h );    // set the hour
54       setMinute( m );  // set the minute
55       setSecond( s );  // set the second
56    }
57
58    // validate and set hour
59    public void setHour( int h )
60    {
61       hour = ( ( h >= 0 && h < 24 ) ? h : 0 );
62    }
63
64    // validate and set minute
65    public void setMinute( int m )
66    {
67       minute = ( ( m >= 0 && m < 60 ) ? m : 0 );
68    }
69
```

Fig. 8.8 Class **Time3** with *set* and *get* methods (part 2 of 3).

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```
70      // validate and set second
71      public void setSecond( int s )
72      {
73         second = ( ( s >= 0 && s < 60 ) ? s : 0 );
74      }
75
76      // Get Methods
77      // get hour value
78      public int getHour()
79      {
80         return hour;
81      }
82
83      // get minute value
84      public int getMinute()
85      {
86         return minute;
87      }
88
89      // get second value
90      public int getSecond()
91      {
92         return second;
93      }
94
95      // convert to String in universal-time format
96      public String toUniversalString()
97      {
98         DecimalFormat twoDigits = new DecimalFormat( "00" );
99
100        return twoDigits.format( getHour() ) + ":" +
101           twoDigits.format( getMinute() ) + ":" +
102           twoDigits.format( getSecond() );
103     }
104
105     // convert to String in standard-time format
106     public String toString()
107     {
108        DecimalFormat twoDigits = new DecimalFormat( "00" );
109
110        return ( ( getHour() == 12 || getHour() == 0 ) ?
111           12 : getHour() % 12 ) + ":" +
112           twoDigits.format( getMinute() ) + ":" +
113           twoDigits.format( getSecond() ) +
114           ( getHour() < 12 ? " AM" : " PM" );
115     }
116
117 }   // end class Time3
```

Fig. 8.8 Class **Time3** with *set* and *get* methods (part 3 of 3).

The new *set* methods of the class are defined in Fig. 8.8 at lines 59–62, 65–68 and 71–74, respectively. Notice that each method performs the same conditional statement that was

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previously in method **setTime** for setting the **hour**, **minute** or **second**. The addition of these methods caused us to redefine the body of method **setTime** to follow *Software Engineering Observation 8.14*—if a method of a class already provides all or part of the functionality required by another method of the class, call that method from the other method. Notice that **setTime** (lines 51–56) now calls methods **setHour**, **setMinute** and **setSecond**—each of which performs part of **setTime**'s task.

The new *get* methods of the class are defined at lines 78–81, 84–87 and 90–93, respectively. Notice that each method simply returns the **hour**, **minute** or **second** value (a copy of each value is returned, because these are all primitive data type variables). The addition of these methods caused us to redefine the bodies of methods **toUniversalString** (lines 96–103) and **toString** (lines 106–115) to follow *Software Engineering Observation 8.14*. In both cases, every use of instance variables **hour**, **minute** and **second** is replaced with a call to **getHour**, **getMinute** and **getSecond**.

Due to the changes in class **Time3** just described, we have minimized the changes that will have to occur in the class definition if the data representation is changed from **hour**, **minute** and **second** to another representation (such as total elapsed seconds in the day). Only the new *set* and *get* method bodies will have to change. This allows the programmer to change the implementation of the class without affecting the clients of the class (as long as all the **public** methods of the class are still called the same way).

The **TimeTest5** applet (Fig. 8.9) provides a graphical user interface that enables the user to exercise the methods of class **Time3**. The user can set the hour, minute or second value by typing a value in the appropriate **JTextField** and pressing the *Enter* key. The user can also click the "**Add 1 to second**" button to increment the time by one second. The **JTextField** and **JButton** events in this applet are all processed in method **actionPerformed** (lines 66–94). Notice that lines 34, 41, 48 and 59 all call **addActionListener** to indicate that the applet should start listening to **JTextField**s **hourField**, **minuteField**, **secondField** and **JButton tickButton**, respectively. Also, notice that all four calls use **this** as the argument, indicating that the object of our applet class **TimeTest5** has its **actionPerformed** method invoked for each user interaction with these four GUI components. This poses an interesting question—how do we determine the GUI component with which the user interacted?

In **actionPerformed**, notice the use of **actionEvent.getSource()** to determine which GUI component generated the event. For example, line 69 determines whether **tickButton** was clicked by the user. If so, the body of the **if** structure executes. Otherwise, the program tests the condition in the **if** structure at line 73, and so on. Every event has a *source*—the GUI component with which the user interacted to signal the program to do a task. The **ActionEvent** parameter contains a reference to the source of the event. The condition in line 69 simply asks, "Is the *source* of the event the **tickButton**?" This condition compares the references on either side of the **==** operator to determine whether they refer to the same object. In this case, if they both refer to the **JButton**, then the program knows that the user pressed the button. Remember that the source of the event calls **actionPerformed** in response to the user interaction.

After each operation, the resulting time is displayed as a string in the status bar of the applet. The output windows in Fig. 8.9 illustrate the applet before and after the following operations: setting the hour to 23, setting the minute to 59, setting the second to 58 and incrementing the second twice with the "**Add 1 to second**" button.

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```
1  // Fig. 8.9: TimeTest5.java
2  // Demonstrating the Time3 class set and get methods.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 // Deitel packages
12 import com.deitel.jhtp4.ch08.Time3;
13
14 public class TimeTest5 extends JApplet
15    implements ActionListener {
16
17    private Time3 time;
18    private JLabel hourLabel, minuteLabel, secondLabel;
19    private JTextField hourField, minuteField,
20       secondField, displayField;
21    private JButton tickButton;
22
23    // Create Time3 object and set up GUI
24    public void init()
25    {
26       time = new Time3();
27
28       Container container = getContentPane();
29       container.setLayout( new FlowLayout() );
30
31       // set up hourLabel and hourField
32       hourLabel = new JLabel( "Set Hour" );
33       hourField = new JTextField( 10 );
34       hourField.addActionListener( this );
35       container.add( hourLabel );
36       container.add( hourField );
37
38       // set up minuteLabel and minuteField
39       minuteLabel = new JLabel( "Set minute" );
40       minuteField = new JTextField( 10 );
41       minuteField.addActionListener( this );
42       container.add( minuteLabel );
43       container.add( minuteField );
44
45       // set up secondLabel and secondField
46       secondLabel = new JLabel( "Set Second" );
47       secondField = new JTextField( 10 );
48       secondField.addActionListener( this );
49       container.add( secondLabel );
50       container.add( secondField );
51
52       // set up displayField
53       displayField = new JTextField( 30 );
```

Fig. 8.9 Using class **Time3**'s *set* and *get* methods (part 1 of 4).

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```
54          displayField.setEditable( false );
55          container.add( displayField );
56
57          // set up tickButton
58          tickButton = new JButton( "Add 1 to Second" );
59          tickButton.addActionListener( this );
60          container.add( tickButton );
61
62          updateDisplay();  // update text in displayField
63       }
64
65       // handle button and text field events
66       public void actionPerformed( ActionEvent actionEvent )
67       {
68          // process tickButton event
69          if ( actionEvent.getSource() == tickButton )
70             tick();
71
72          // process hourField event
73          else if ( actionEvent.getSource() == hourField ) {
74             time.setHour(
75                Integer.parseInt( actionEvent.getActionCommand() ) );
76             hourField.setText( "" );
77          }
78
79          // process minuteField event
80          else if ( actionEvent.getSource() == minuteField ) {
81             time.setMinute(
82                Integer.parseInt( actionEvent.getActionCommand() ) );
83             minuteField.setText( "" );
84          }
85
86          // process secondField event
87          else if ( actionEvent.getSource() == secondField ) {
88             time.setSecond(
89                Integer.parseInt( actionEvent.getActionCommand() ) );
90             secondField.setText( "" );
91          }
92
93          updateDisplay();  // update displayField and status bar
94       }
95
96       // update displayField and applet container's status bar
97       public void updateDisplay()
98       {
99          displayField.setText( "Hour: " + time.getHour() +
100            "; Minute: " + time.getMinute() +
101            "; Second: " + time.getSecond() );
102
103         showStatus( "Standard time is: " + time.toString() +
104            "; Universal time is: " + time.toUniversalString() );
105      }
106
```

Fig. 8.9 Using class **Time3**'s *set* and *get* methods (part 2 of 4).

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```
107     // add one to second and update hour/minute if necessary
108     public void tick()
109     {
110        time.setSecond( ( time.getSecond() + 1 ) % 60 );
111
112        if ( time.getSecond() == 0 ) {
113           time.setMinute( ( time.getMinute() + 1 ) % 60 );
114
115           if ( time.getMinute() == 0 )
116              time.setHour( ( time.getHour() + 1 ) % 24 );
117        }
118     }
119
120  }  // end class TimeTest5
```

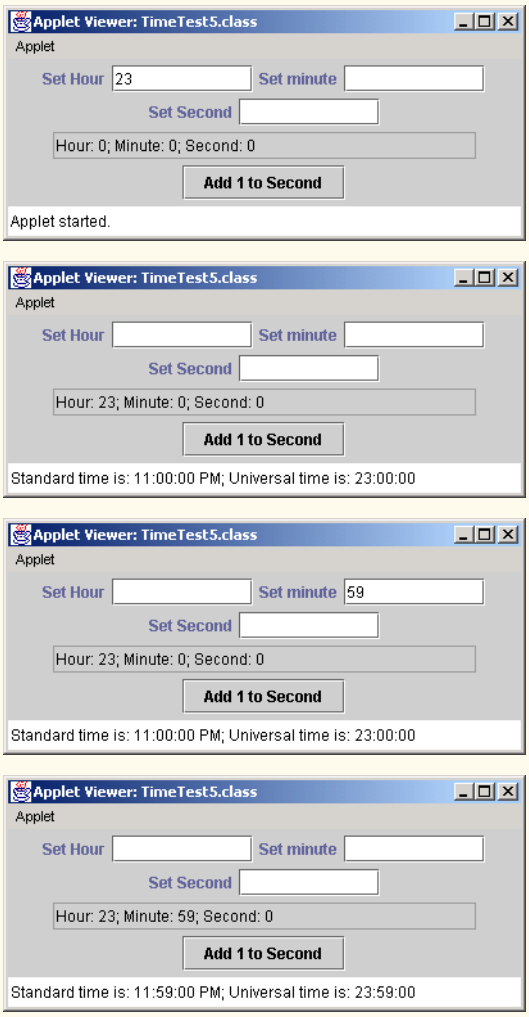

Fig. 8.9 Using class **Time3**'s *set* and *get* methods (part 3 of 4).

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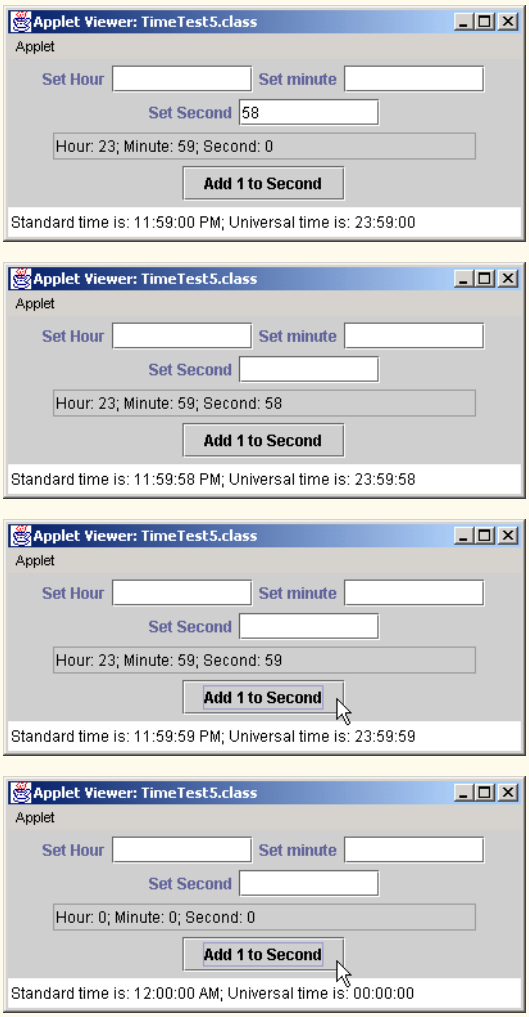

Fig. 8.9 Using class **`Time3`**'s *set* and *get* methods (part 4 of 4).

Note that when the "**`Add 1 to second`**" button is clicked, method **`actionPerformed`** calls the applet's **`tick`** method (defined at lines 108–118). Method **`tick`** uses all the new *set* and *get* methods to increment the second properly. Although this works, it incurs the performance burden of issuing multiple method calls. In Section 8.12, we discuss the notion of package access as a means of eliminating this performance burden.

Common Programming Error 8.8

A constructor can call other methods of the class, such as set *or* get *methods. However, the instance variables might not yet be in a consistent state, because the constructor is in the process of initializing the object. Using instance variables before they have been initialized properly is a logic error.*

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Set methods are certainly important from a software engineering standpoint, because they can perform validity checking. *Set* and *get* methods have another important software engineering advantage, discussed in the following *Software Engineering Observation*.

Software Engineering Observation 8.16

Accessing **`private`** *data through* set *and* get *methods not only protects the instance variables from receiving invalid values, but also insulates clients of the class from the representation of the instance variables. Thus, if the representation of the data changes (typically, to reduce the amount of storage required, improve performance or enhance the class in other ways), only the method implementations need to change—the clients need not change as long as the interface provided by the methods remains the same.*

8.8.1 Executing an Applet that Uses Programmer-Defined Packages

After compiling the classes in Fig. 8.8 and Fig. 8.9, you can execute the applet from a command window with the command

```
appletviewer TimeTest5.html
```

As we discussed when we introduced packages earlier in this chapter, the interpreter can locate packaged classes in the current directory. The **`appletviewer`** is a Java application that executes a Java applet. Like the interpreter, the **`appletviewer`** can load standard Java classes and extension classes installed on the local computer. However, the **`appletviewer`** does not use the class path to locate classes in programmer-defined packages. For an applet, such classes should be bundled with the applet class in an archive file called a *Java Archive (JAR)* file. Remember that applets normally are downloaded from the Internet into a Web browser (see Chapter 3 for more information). Bundling the classes and packages that compose an applet enables the applet and its supporting classes to be downloaded as a unit, then executed in the browser (or via the Java Plug-in for browsers that do not support Java 2).

To bundle the classes in Fig. 8.8 and Fig. 8.9, open a command window and change directories to the location in which **`TimeTest5.class`** is stored. In that same directory should be the **`com`** directory that begins the package directory structure for class **`Time3`**. In that directory, issue the following command

```
jar cf TimeTest5.jar TimeTest5.class com\*.*
```

to create the JAR file. [*Note:* This command uses **`\`** as the directory separator from the MS-DOS prompt. UNIX would use **`/`** as the directory separator.] In the preceding command, **`jar`** is the *Java archive utility* used to create JAR files. Next are the options for the **`jar`** utility—***`cf`***. The letter ***`c`*** indicates that we are creating a JAR file. The letter ***`f`*** indicates that the next argument in the command line (**`TimeTest5.jar`**) is the name of the JAR file to create. Following the options and JAR file name are the actual files that will be included in the JAR file. We specified **`TimeTest5.class`** and **`com\*.*`**, indicating that **`TimeTest5.class`** and all the files in the **`com`** directory should be included in the JAR file. The **`com`** directory begins the package that contains the **`.class`** file for the **`Time3`**. [*Note:* You can include selected files by specifying the path and file name for each individ-

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ual file.] It is important that the directory structure in the JAR file match the directory structure for the packaged classes. Therefore, we executed the **jar** command from the directory in which **com** is located.

To confirm that the files were archived directly, you can issue the command

```
jar tvf TimeTest5.jar
```

which produces the listing in Fig. 8.10. In the preceding command, the options for the **jar** utility are ***tvf***. The letter ***t*** indicates that the table of contents for the JAR should be listed. The letter ***v*** indicates that the output should be verbose (the verbose output includes the file size in bytes and the date and time each file was created, in addition to the directory structure and file name). The letter ***f*** specifies that the next argument on the command line is the JAR file to use.

The only remaining issue is to specify the archive as part of the applet's HTML file. In prior examples, **<applet>** tags had the form

```
<applet code = "ClassName.class" width = "width" height = "height">
</applet>
```

To specify that the applet classes are located in a JAR file, use an **<applet>** tag of the form:

```
<applet code = "ClassName.class" archive = "archiveList"
   width = "width" height = "height">
</applet>
```

The ***archive*** *attribute* can specify a comma-separated list of archive files for use in an applet. Each file in the **archive** list will be downloaded by the browser when it encounters the **<applet>** tags in the HTML document. For the TimeTest5 applet, the applet tag would be

```
<applet code = "TimeTest5.class" archive = "TimeTest5.jar"
   width = "400" height = "115">
</applet>
```

Try loading this applet into your Web browser. Remember that you *must* either have a browser that supports Java 2 (such as Netscape Navigator 6) or convert the HTML file for use with the Java Plug-in (as discussed in Chapter 3).

```
   0 Fri May 25 14:13:14 EDT 2001 META-INF/
  71 Fri May 25 14:13:14 EDT 2001 META-INF/MANIFEST.MF
2959 Fri May 25 13:42:32 EDT 2001 TimeTest5.class
   0 Fri May 18 17:35:18 EDT 2001 com/deitel/
   0 Fri May 18 17:35:18 EDT 2001 com/deitel/jhtp4/
   0 Fri May 18 17:35:18 EDT 2001 com/deitel/jhtp4/ch08/
1765 Fri May 18 17:35:18 EDT 2001 com/deitel/jhtp4/ch08/Time3.class
```

Fig. 8.10 Contents of **TimeTest5.jar**.

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8.9 Software Reusability

Java programmers concentrate on crafting new classes and reusing existing classes. Many *class libraries* exist, and others are being developed worldwide. Software is then constructed from existing, well-defined, carefully tested, well-documented, portable, widely available components. This kind of software reusability speeds the development of powerful, high-quality software. *Rapid applications development (RAD)* is of great interest today.

Java programmers now have thousands of classes in the Java API from which to choose to help them implement Java programs. Indeed, Java is not just a programming language. It is a framework in which Java developers can work to achieve true reusability and rapid applications development. Java programmers can focus on the task at hand when developing their programs and leave the lower-level details to the classes of the Java API. For example, to write a program that draws graphics, a Java programmer does not require knowledge of graphics on every computer platform where the program will execute. Instead, a Java programmer concentrates on learning Java's graphics capabilities (which are quite substantial and growing) and writes a Java program that draws the graphics, using Java's API classes such as **`Graphics`**. When the program executes on a given computer, it is the job of the interpreter to translate Java commands into commands that the local computer can understand.

The Java API classes enable Java programmers to bring new applications to market faster by using preexisting, tested components. Not only does this reduce development time, it also improves programmers' ability to debug and maintain applications. To take advantage of Java's many capabilities, it is essential that programmers take the time to familiarize themselves with the variety of packages and classes in the Java API. There are many Web-based resources at java.sun.com to help you with this task. The primary resource for learning about the Java API is the *Java API documentation*, which can be found at

```
java.sun.com/j2se/1.3/docs/api/index.html
```

In addition, **`java.sun.com`** provides many other resources, including tutorials, articles and sites specific to individual Java topics. Java developers should also register (for free) at the Java Developer Connection

```
developer.java.sun.com
```

This site provides additional resources that Java developers will find useful, including more tutorials and articles, and links to other Java resources. See Appendix B for a more complete list of Java-related Internet and World Wide Web resources.

Good Programming Practice 8.6

Avoid reinventing the wheel. Study the capabilities of the Java API. If the API already contains a class that meets the requirements of your program, use that class rather than creating your own.

In general, to realize the full potential of software reusability, we need to improve cataloging schemes, licensing schemes, protection mechanisms that ensure master copies of classes are not corrupted, description schemes that system designers use to determine if existing objects meet their needs, browsing mechanisms that determine what classes are

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available and how closely they meet software developer requirements, and the like. Many interesting research and development problems have been solved and many more need to be solved; these problems will be solved because the potential value of software reuse is enormous.

8.10 Final Instance Variables

We have emphasized repeatedly the *principle of least privilege* as one of the most fundamental principles of good software engineering. Let us see one way in which this principle applies to instance variables.

Some instance variables need to be modifiable and some do not. The programmer can use the keyword **final** to specify that a variable is not modifiable and that any attempt to modify the variable is an error. For example,

```
private final int INCREMENT = 5;
```

declares a constant instance variable **INCREMENT** of type **int** and initializes it to 5.

Software Engineering Observation 8.17

*Declaring an instance variable as **final** helps enforce the principle of least privilege. If an instance variable should not be modified, declare it to be **final** to expressly forbid modification.*

Testing and Debugging Tip 8.3

*Accidental attempts to modify a **final** instance variable are caught at compile time rather than causing execution-time errors. It is always preferable to get bugs out at compile time, if possible, rather than allowing them to slip through to execution time (where studies have found that the cost of repair is often as much as ten times more expensive).*

Common Programming Error 8.9

*Attempting to modify a **final** instance variable after it is initialized is a syntax error.*

The applet of Fig. 8.11 creates a **final** instance variable **INCREMENT** of type **int** and initializes it to 5 in its declaration (line 15). A **final** variable cannot be modified by assignment after it is initialized. Such a variable can be initialized in its declaration or in every constructor of the class.

Common Programming Error 8.10

*Not initializing a **final** instance variable in its declaration or in every constructor of the class is a syntax error.*

```
1  // Fig. 8.11: Increment.java
2  // Initializing a final variable
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
```

Fig. 8.11 Initializing a **final** variable (part 1 of 2).

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```
 8  // Java extension packages
 9  import javax.swing.*;
10
11  public class Increment extends JApplet
12     implements ActionListener {
13
14     private int count = 0, total = 0;
15     private final int INCREMENT = 5;   // constant variable
16
17     private JButton button;
18
19     // set up GUI
20     public void init()
21     {
22        Container container = getContentPane();
23
24        button = new JButton( "Click to increment" );
25        button.addActionListener( this );
26        container.add( button );
27     }
28
29     // add INCREMENT to total when user clicks button
30     public void actionPerformed( ActionEvent actionEvent )
31     {
32        total += INCREMENT;
33        count++;
34        showStatus( "After increment " + count +
35           ": total = " + total );
36     }
37
38  }  // end class Increment
```

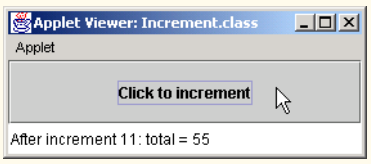

Fig. 8.11 Initializing a **final** variable (part 2 of 2).

Figure 8.12 illustrates compiler errors produced for the program of Fig. 8.11 if instance variable **INCREMENT** is declared **final**, but is not initialized in the declaration.

```
Increment.java:11: variable INCREMENT might not have been
   initialized
public class Increment extends JApplet
       ^
1 error
```

Fig. 8.12 Compiler error message as a result of not initializing increment.

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8.11 Composition: Objects as Instance Variables of Other Classes

An **AlarmClock** class object needs to know when it is supposed to sound its alarm, so why not include a reference to a **Time** object as a member of the **AlarmClock** object? Such a capability is called *composition*. A class can have references to objects of other classes as members.

Software Engineering Observation 8.18

One form of software reuse is composition, in which a class has references to objects of other classes as members.

The next program contains three classes—**Date** (Fig. 8.13), **Employee** (Fig. 8.14) and **EmployeeTest** (Fig. 8.15). Class **Employee** contains instance variables **firstName**, **lastName**, **birthDate** and **hireDate**. Members **birthDate** and **hireDate** are references to **Date**s that contain instance variables **month**, **day** and **year**. This demonstrates that a class can contain references to objects of other classes. Class **EmployeeTest** instantiates an **Employee** and initializes and displays its instance variables. The **Employee** constructor (Fig. 8.14, lines 12–20) takes eight arguments—**first**, **last**, **birthMonth**, **birthDay**, **birthYear**, **hireMonth**, **hireDay** and **hireYear**. Arguments **birthMonth**, **birthDay** and **birthYear** are passed to the **Date** constructor (Fig. 8.13, lines 13–28) to initialize the **birthDate** object and **hireMonth**, **hireDay** and **hireYear** are passed to the **Date** constructor to initialize the **hireDate** object.

A member object does not need to be initialized immediately with constructor arguments. If an empty argument list is provided when a member object is created, the object's default constructor (or no-argument constructor if one is available) will be called automatically. Values, if any, established by the default constructor (or no-argument constructor) can then be replaced by *set* methods.

Performance Tip 8.2

Initialize member objects explicitly at construction time by passing appropriate arguments to the constructors of the member objects. This eliminates the overhead of initializing member objects twice—once when the member object's default constructor is called and again when set *methods are used to provide initial values for the member object.*

Note that both class **Date** (Fig. 8.13) and class **Employee** (Fig. 8.14) are defined as part of the package **com.deitel.jhtp4.ch08** as specified on line 3 of each file. Because they are in the same package (i.e., the same directory), class **Employee** does not need to import class **Date** to use it. When the compiler searches for the file **Date.class**, the compiler knows to search the directory where **Employee.class** is located. Classes in a package never need to import other classes from the same package.

```
1  // Fig. 8.13: Date.java
2  // Declaration of the Date class.
3  package com.deitel.jhtp4.ch08;
4
5  public class Date extends Object {
6     private int month;  // 1-12
```

Fig. 8.13 **Date** class (part 1 of 2).

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```
 7     private int day;     // 1-31 based on month
 8     private int year;    // any year
 9
10     // Constructor: Confirm proper value for month;
11     // call method checkDay to confirm proper
12     // value for day.
13     public Date( int theMonth, int theDay, int theYear )
14     {
15        if ( theMonth > 0 && theMonth <= 12 )  // validate month
16           month = theMonth;
17        else {
18           month = 1;
19           System.out.println( "Month " + theMonth +
20              " invalid. Set to month 1." );
21        }
22
23        year = theYear;                  // could validate year
24        day = checkDay( theDay );        // validate day
25
26        System.out.println(
27           "Date object constructor for date " + toString() );
28     }
29
30     // Utility method to confirm proper day value
31     // based on month and year.
32     private int checkDay( int testDay )
33     {
34        int daysPerMonth[] =
35           { 0, 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30, 31 };
36
37        // check if day in range for month
38        if ( testDay > 0 && testDay <= daysPerMonth[ month ] )
39           return testDay;
40
41        // check for leap year
42        if ( month == 2 && testDay == 29 &&
43             ( year % 400 == 0 ||
44               ( year % 4 == 0 && year % 100 != 0 ) ) )
45           return testDay;
46
47        System.out.println( "Day " + testDay +
48           " invalid. Set to day 1." );
49
50        return 1;  // leave object in consistent state
51     }
52
53     // Create a String of the form month/day/year
54     public String toString()
55     {
56        return month + "/" + day + "/" + year;
57     }
58
59  }  // end class Date
```

Fig. 8.13 **Date** class (part 2 of 2).

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```
1  // Fig. 8.14: Employee.java
2  // Definition of class Employee.
3  package com.deitel.jhtp4.ch08;
4
5  public class Employee extends Object {
6     private String firstName;
7     private String lastName;
8     private Date birthDate;
9     private Date hireDate;
10
11    // constructor to initialize name, birth date and hire date
12    public Employee( String first, String last,
13       int birthMonth, int birthDay, int birthYear,
14       int hireMonth, int hireDay, int hireYear )
15    {
16       firstName = first;
17       lastName = last;
18       birthDate = new Date( birthMonth, birthDay, birthYear );
19       hireDate = new Date( hireMonth, hireDay, hireYear );
20    }
21
22    // convert Employee to String format
23    public String toString()
24    {
25       return lastName + ", " + firstName +
26          "  Hired: " + hireDate.toString() +
27          "  Birthday: " + birthDate.toString();
28    }
29
30 }  // end class Employee
```

Fig. 8.14 **Employee** class with member object references.

```
1  // Fig. 8.15: EmployeeTest.java
2  // Demonstrating an object with a member object.
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  // Deitel packages
8  import com.deitel.jhtp4.ch08.Employee;
9
10 public class EmployeeTest {
11
12    // test class Employee
13    public static void main( String args[] )
14    {
15       Employee employee = new Employee( "Bob", "Jones",
16          7, 24, 49, 3, 12, 88 );
17
```

Fig. 8.15 Demonstrating an object with a member object reference (part 1 of 2).

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```
18         JOptionPane.showMessageDialog( null,
19            employee.toString(), "Testing Class Employee",
20            JOptionPane.INFORMATION_MESSAGE );
21
22         System.exit( 0 );
23      }
24
25   }  // end class EmployeeTest
```

```
Date object constructor for date 7/24/1949
Date object constructor for date 3/12/1988
```

Fig. 8.15 Demonstrating an object with a member object reference (part 2 of 2).

8.12 Package Access

When no member access modifier is provided for a method or variable when it is defined in a class, the method or variable is considered to have *package access*. If your program consists of one class definition, this has no specific effects on the program. However, if your program uses multiple classes from the same package (i.e., a group of related classes), these classes can access each other's package-access methods and data directly through a reference to an object.

Performance Tip 8.3

Package access enables objects of different classes to interact without the need for set *and* get *methods that provide access to data, thus eliminating some of the method call overhead.*

Let us consider a mechanical example of package access. The application of Fig. 8.16 contains two classes—the **PackageDataTest** application class (lines 8–34) and the **PackageData** class (lines 37–54). In the **PackageData** class definition, lines 38–39 declare the instance variables **number** and **string** with no member access modifiers; therefore, these are package access instance variables. The **PackageDataTest** application's **main** method creates an instance of the **PackageData** class (line 13) to demonstrate the ability to modify the **PackageData** instance variables directly (as shown on lines 20–21). The results of the modification can be seen in the output window.

When you compile this program, the compiler produces two separate files—a **.class** file for class **PackageData** and a **.class** file for class **PackageDataTest**. Every Java class has its own **.class** file. These two **.class** files are placed in the same directory by the compiler automatically and are considered to be part of the same package (they are certainly related by the fact that they are in the same file). Because they are part of the same package, class **PackageDataTest** is allowed to modify the package access data of objects of class **PackageData**.

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```
1  // Fig. 8.16: PackageDataTest.java
2  // Classes in the same package (i.e., the same directory) can
3  // use package access data of other classes in the same package.
4
5  // Java extension packages
6  import javax.swing.JOptionPane;
7
8  public class PackageDataTest {
9
10    // Java extension packages
11    public static void main( String args[] )
12    {
13       PackageData packageData = new PackageData();
14
15       // append String representation of packageData to output
16       String output =
17          "After instantiation:\n" + packageData.toString();
18
19       // change package access data in packageData object
20       packageData.number = 77;
21       packageData.string = "Good bye";
22
23       // append String representation of packageData to output
24       output += "\nAfter changing values:\n" +
25          packageData.toString();
26
27       JOptionPane.showMessageDialog( null, output,
28          "Demonstrating Package Access",
29          JOptionPane.INFORMATION_MESSAGE );
30
31       System.exit( 0 );
32    }
33
34 }  // end class PackageDataTest
35
36 // class with package access instance variables
37 class PackageData {
38    int number;     // package access instance variable
39    String string;  // package access instance variable
40
41    // constructor
42    public PackageData()
43    {
44       number = 0;
45       string = "Hello";
46    }
47
48    // convert PackageData object to String representation
49    public String toString()
50    {
51       return "number: " + number + "    string: " + string;
52    }
53
```

Fig. 8.16 Package access to members of a class (part 1 of 2).

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```
54 } // end class PackageData
```

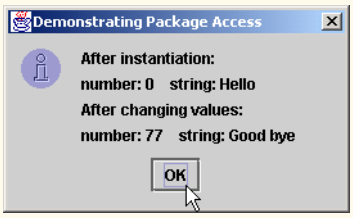

Fig. 8.16 Package access to members of a class (part 2 of 2).

Software Engineering Observation 8.19

Some people in the OOP community feel that package access corrupts information hiding and weakens the value of the object-oriented design approach, because the programmer must assume responsibility for error checking and data validation in any code that manipulates the package access data members.

8.13 Using the `this` Reference

When a method of a class references another member of that class for a specific object of that class, how does Java ensure that the proper object is referenced? The answer is that each object has access to a reference to itself—called the ***this*** *reference*.

The **this** reference is used implicitly to refer to both the instance variables and methods of an object. We begin with a simple example of using the **this** reference explicitly; a subsequent example shows some substantial and subtle examples of using **this**.

Performance Tip 8.4

Java conserves storage by maintaining only one copy of each method per class; this method is invoked by every object of that class. Each object, on the other hand, has its own copy of the class's instance variables.

The application of Fig. 8.17 demonstrates implicit and explicit use of the **this** reference to enable the **main** method of class **ThisTest** to display the **private** data of a **SimpleTime** object.

```
1  // Fig. 8.17: ThisTest.java
2  // Using the this reference to refer to
3  // instance variables and methods.
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  // Java extension packages
9  import javax.swing.*;
10
```

Fig. 8.17 Using the **this** reference implicitly and explicitly (part 1 of 3).

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```
11  public class ThisTest {
12
13     // test class SimpleTime
14     public static void main( String args[] )
15     {
16        SimpleTime time = new SimpleTime( 12, 30, 19 );
17
18        JOptionPane.showMessageDialog( null, time.buildString(),
19           "Demonstrating the \"this\" Reference",
20           JOptionPane.INFORMATION_MESSAGE );
21
22        System.exit( 0 );
23     }
24
25  }  // end class ThisTest
26
27  // class SimpleTime demonstrates the "this" reference
28  class SimpleTime {
29     private int hour, minute, second;
30
31     // constructor uses parameter names identical to instance
32     // variable names, so "this" reference required to distinguish
33     // between instance variables and parameters
34     public SimpleTime( int hour, int minute, int second )
35     {
36        this.hour = hour;       // set "this" object's hour
37        this.minute = minute;   // set "this" object's minute
38        this.second = second;   // set "this" object's second
39     }
40
41     // call toString explicitly via "this" reference, explicitly
42     // via implicit "this" reference, implicitly via "this"
43     public String buildString()
44     {
45        return "this.toString(): " + this.toString() +
46           "\ntoString(): " + toString() +
47           "\nthis (with implicit toString() call): " + this;
48     }
49
50     // convert SimpleTime to String format
51     public String toString()
52     {
53        DecimalFormat twoDigits = new DecimalFormat( "00" );
54
55        // "this" not required, because toString does not have
56        // local variables with same names as instance variables
57        return twoDigits.format( this.hour ) + ":" +
58           twoDigits.format( this.minute ) + ":" +
59           twoDigits.format( this.second );
60     }
61
62  }  // end class SimpleTime
```

Fig. 8.17 Using the **this** reference implicitly and explicitly (part 2 of 3).

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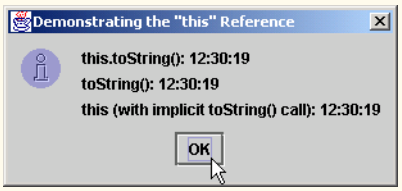

Fig. 8.17 Using the **this** reference implicitly and explicitly (part 3 of 3).

Class **SimpleTime** (lines 8–60) defines three **private** instance variables—**hour**, **minute** and **second**. The constructor (lines 34–39) receives three **int** arguments to initialize a **SimpleTime** object. Notice that the parameter names for the constructor are the same as the instance variable names. Remember that a local variable of a method with the same name as an instance variable of a class hides the instance variable in the scope of the method. For this reason, we use the **this** reference to refer explicitly to the instance variables on lines 36–38.

Common Programming Error 8.11

*In a method in which a method parameter has the same name as one of the class members, use **this** explicitly if you want to access the class member; otherwise, you will incorrectly reference the method parameter.*

Good Programming Practice 8.7

Avoid using method parameter names that conflict with class member names.

Method **buildString** (lines 43–48) returns a **String** created with a statement that uses the **this** reference three ways. Line 45 explicitly invokes the class's **toString** method via **this.toString()**. Line 46 implicitly uses the **this** reference to perform the same task. Line 47 appends **this** to the string that will be returned. Remember that the **this** reference is a reference to an object—the current **SimpleTime** object being manipulated. As before, any reference added to a **String** results in a call to the **toString** method for the referenced object. Method **buildString** is invoked at line 18 to display the results of the three calls to **toString**. Note that the same time is displayed on all three lines of the output because all three calls to **toString** are for the same object.

Another use of the **this** reference is in enabling *concatenated method calls* (also called *cascaded method calls* or *method call chaining*). Figure 8.18 illustrates returning a reference to a **Time4** object to enable method calls of class **Time4** to be concatenated. Methods **setTime** (lines 50–57), **setHour** (lines 60–65), **setMinute** (line 68–74) and **setSecond** (lines 77–83) each have a return type of **Time4** and each has as its last statement

```
return this;
```

to indicate that a reference to the **Time4** object being manipulated should be returned to the caller of the method.

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```
1  // Fig. 8.18: Time4.java
2  // Time4 class definition
3  package com.deitel.jhtp4.ch08;
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  public class Time4 extends Object {
9     private int hour;     // 0 - 23
10    private int minute;   // 0 - 59
11    private int second;   // 0 - 59
12
13    // Time4 constructor initializes each instance variable
14    // to zero. Ensures that Time object starts in a
15    // consistent state.
16    public Time4()
17    {
18       this.setTime( 0, 0, 0 );
19    }
20
21    // Time4 constructor: hour supplied, minute and second
22    // defaulted to 0
23    public Time4( int hour )
24    {
25       this.setTime( hour, 0, 0 );
26    }
27
28    // Time4 constructor: hour and minute supplied, second
29    // defaulted to 0
30    public Time4( int hour, int minute )
31    {
32       this.setTime( hour, minute, 0 );
33    }
34
35    // Time4 constructor: hour, minute and second supplied
36    public Time4( int hour, int minute, int second )
37    {
38       this.setTime( hour, minute, second );
39    }
40
41    // Time4 constructor: another Time4 object supplied.
42    public Time4( Time4 time )
43    {
44       this.setTime( time.getHour(), time.getMinute(),
45          time.getSecond() );
46    }
47
48    // Set Methods
49    // set a new Time value using universal time
50    public Time4 setTime( int hour, int minute, int second )
51    {
52       this.setHour( hour );      // set hour
```

Fig. 8.18 Class **Time4** using **this** to enable chained method calls (part 1 of 3).

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```
53          this.setMinute( minute );  // set minute
54          this.setSecond( second );  // set second
55
56          return this;     // enables chaining
57       }
58
59       // validate and set hour
60       public Time4 setHour( int hour )
61       {
62          this.hour = ( hour >= 0 && hour < 24 ? hour : 0 );
63
64          return this;     // enables chaining
65       }
66
67       // validate and set minute
68       public Time4 setMinute( int minute )
69       {
70          this.minute =
71             ( minute >= 0 && minute < 60 ) ? minute : 0;
72
73          return this;     // enables chaining
74       }
75
76       // validate and set second
77       public Time4 setSecond( int second )
78       {
79          this.second =
80             ( second >= 0 && second < 60 ) ? second : 0;
81
82          return this;     // enables chaining
83       }
84
85       // Get Methods
86       // get value of hour
87       public int getHour() { return this.hour; }
88
89       // get value of minute
90       public int getMinute() { return this.minute; }
91
92       // get value of second
93       public int getSecond() { return this.second; }
94
95       // convert to String in universal-time format
96       public String toUniversalString()
97       {
98          DecimalFormat twoDigits = new DecimalFormat( "00" );
99
100         return twoDigits.format( this.getHour() ) + ":" +
101            twoDigits.format( this.getMinute() ) + ":" +
102            twoDigits.format( this.getSecond() );
103      }
104
```

Fig. 8.18 Class **Time4** using **this** to enable chained method calls (part 2 of 3).

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```
105    // convert to String in standard-time format
106    public String toString()
107    {
108       DecimalFormat twoDigits = new DecimalFormat( "00" );
109
110       return ( this.getHour() == 12 || this.getHour() == 0 ?
111          12 : this.getHour() % 12 ) + ":" +
112          twoDigits.format( this.getMinute() ) + ":" +
113          twoDigits.format( this.getSecond() ) +
114          ( this.getHour() < 12 ? " AM" : " PM" );
115    }
116
117 }  // end class Time4
```

Fig. 8.18 Class **Time4** using **this** to enable chained method calls (part 3 of 3).

The example again demonstrates the explicit use of the **this** reference inside the body of a class. In class **Time4**, every use of an instance variable of the class and every call to another method in class **Time4** uses the **this** reference explicitly. Most programmers prefer not to use the **this** reference unless it is required or helps clarify a piece of code.

Good Programming Practice 8.8

*Explicitly using **this** can increase program clarity in some contexts in which **this** is optional.*

In application class **TimeTest6** (Fig. 8.19), line 18 and line 26 both demonstrate method call chaining. Why does the technique of returning the **this** reference work? Let us discuss line 18. The dot operator (**.**) associates from left to right, so the expression

```
time.setHour( 18 ).setMinute( 30 ).setSecond( 22 );
```

first evaluates **time.setHour(18)**, then returns a reference to object **time** as the result of this method call. Any time you have a reference in a program (even as the result of a method call), the reference can be followed by a dot operator and a call to one of the methods of the reference type. Thus, the remaining expression is interpreted as

```
time.setMinute( 30 ).setSecond( 22 );
```

The **time.setMinute(30)** call executes and returns a reference to **time**. The remaining expression is interpreted as

```
time.setSecond( 22 );
```

When the statement is complete, the time is **18** for the **hour**, **30** for the **minute** and **22** from the **second**.

Note that the calls on line 26

```
time.setTime( 20, 20, 20 ).toString();
```

also use the concatenation feature. These method calls must appear in this order in this expression because **toString** as defined in the class does not return a reference to a **Time4** object. Placing the call to **toString** before the call to **setTime** causes a syntax error. Note that **toString** returns a reference to a **String** object. Therefore, a method of class **String** could be concatenated to the end of line 26.

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```
1  // Fig. 8.19: TimeTest6.java
2  // Chaining method calls together with the this reference
3
4  // Java extension packages
5  import javax.swing.*;
6
7  // Deitel packages
8  import com.deitel.jhtp4.ch08.Time4;
9
10 public class TimeTest6 {
11
12    // test method call chaining with object of class Time4
13    public static void main( String args[] )
14    {
15       Time4 time = new Time4();
16
17       // chain calls to setHour, setMinute and setSecond
18       time.setHour( 18 ).setMinute( 30 ).setSecond( 22 );
19
20       // use method call chaining to set new time and get
21       // String representation of new time
22       String output =
23          "Universal time: " + time.toUniversalString() +
24          "\nStandard time: " + time.toString() +
25          "\n\nNew standard time: " +
26          time.setTime( 20, 20, 20 ).toString();
27
28       JOptionPane.showMessageDialog( null, output,
29          "Chaining Method Calls",
30          JOptionPane.INFORMATION_MESSAGE );
31
32       System.exit( 0 );
33    }
34
35 }  // end class TimeTest6
```

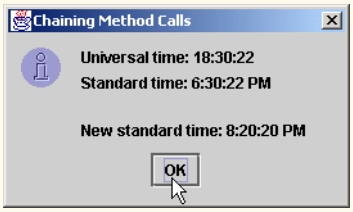

Fig. 8.19 Concatenating method calls.

Note that the purpose of the example in Fig. 8.18 and Fig. 8.19 is to demonstrate the mechanics of concatenated method calls. Many Java methods return references to objects that can be used in the manner shown here. It is important to understand concatenated method calls as they appear frequently in Java programs.

Good Programming Practice 8.9

For program clarity, avoid using concatenated method calls.

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8.14 Finalizers

We have seen that constructor methods are capable of initializing data in an object of a class when the class is created. Often, constructors acquire various system resources such as memory (when the **new** operator is used). We need a disciplined way to give resources back to the system when they are no longer needed to avoid resource leaks. The most common resource acquired by constructors is memory. Java performs automatic *garbage collection* of memory to help return memory back to the system. When an object is no longer used in the program (i.e., there are no references to the object), the object is *marked for garbage collection*. The memory for such an object can be reclaimed when the *garbage collector* executes. Therefore, memory leaks that are common in other languages like C and C++ (because memory is not automatically reclaimed in those languages) are less likely to happen in Java. However, other resource leaks can occur.

Performance Tip 8.5

Extensive use of local variables that refer to objects can degrade performance. When a local variable is the only reference to an object, the object is marked for garbage collection as the local variable goes out of scope. If this happens frequently in short time periods, large numbers of objects could be marked for garbage collection, thus placing a performance burden on the garbage collector.

Every class in Java can have a *finalizer method* that returns resources to the system. The finalizer method for an object is guaranteed to be called to perform *termination housekeeping* on the object just before the garbage collector reclaims the memory for the object. A class's finalizer method always has the name **finalize**, receives no parameters and returns no value (i.e., its return type is **void**). A class should have only one **finalize** method that takes no arguments. Method **finalize** is defined originally in class **Object** as a placeholder that does nothing. This guarantees that every class has a **finalize** method for the garbage collector to call.

Good Programming Practice 8.10

The last statement in a **finalize** *method should always be* **super.finalize();** *to ensure that the superclass's* **finalize** *method is called.*

Software Engineering Observation 8.20

The garbage collector is not guaranteed to execute; therefore, an object's **finalize** *method is not guaranteed to get called. You should not architect classes that rely on the garbage collector calling an object's* **finalize** *method to deallocate resources.*

Finalizers have not been provided for the classes presented so far. Actually, finalizers are rarely used in industrial Java applications. We will see a sample **finalize** method and discuss the garbage collector further in Figure 8.20.

Testing and Debugging Tip 8.4

Several professional Java developers who reviewed this book indicated that method **finalize** *is not useful in industrial Java applications, because it is not guaranteed to get called. For this reason, you should search your Java programs for any use of method* **finalize** *to ensure that the program does not rely on calls to method* **finalize** *for proper deallocation of resources. In fact, you might consider removing method* **finalize** *entirely and*

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using other techniques to ensure proper resource deallocation. We present one such technique in Chapter 14, Exception Handling.

8.15 Static Class Members

Each object of a class has its own copy of all the instance variables of the class. In certain cases, only one copy of a particular variable should be shared by all objects of a class. A ***static*** *class variable* is used for these and other reasons. A **static** class variable represents *class-wide information*—all objects of the class share the same piece of data. The declaration of a **static** member begins with the keyword **static**.

Let us motivate the need for **static** class-wide data with a video game example. Suppose we have a video game with **Martian**s and other space creatures. Each **Martian** tends to be brave and willing to attack other space creatures when the **Martian** is aware that there are at least five **Martian**s present. If there are fewer than five **Martian**s present, each **Martian** becomes cowardly. So each **Martian** needs to know the **martianCount**. We could endow class **Martian** with **martianCount** as instance data. If we do this, then every **Martian** will have a separate copy of the instance data and every time we create a new **Martian** we will have to update the instance variable **martianCount** in every **Martian**. This wastes space with the redundant copies and wastes time in updating the separate copies. Instead, we declare **martianCount** to be **static**. This makes **martianCount** class-wide data. Every **Martian** can see the **martianCount** as if it were instance data of the **Martian**, but only one copy of the static **martianCount** is maintained by Java. This saves space. We save time by having the **Martian** constructor increment the static **martianCount**. Because there is only one copy, we do not have to increment separate copies of **martianCount** for each **Martian** object.

Performance Tip 8.6

*Use **static** class variables to save storage when a single copy of the data will suffice.*

Although **static** class variables may seem like global variables, **static** class variables have class scope. A class's **public static** class members can be accessed through a reference to any object of that class, or they can be accessed through the class name by using the dot operator (e.g., **Math.random()**). A class's **private static** class members can be accessed only through methods of the class. Actually, **static** class members exist even when no objects of that class exist—they are available as soon as the class is loaded into memory at execution time. To access a **public static** class member when no objects of the class exist, simply prefix the class name and the dot operator to the class member. To access a **private static** class member when no objects of the class exist, a **public static** method must be provided and the method must be called by prefixing its name with the class name and dot operator.

Our next program defines two classes—**Employee** (Fig. 8.20) and **EmployeeTest** (Fig. 8.21). Class **Employee** defines a **private static** class variable and a **public static** method. The class variable **count** (Fig. 8.20, line 6) is initialized to zero by default. Class variable **count** maintains a count of the number of objects of class **Employee** that have been instantiated and currently reside in memory. This includes objects that have already been marked for garbage collection but have not yet been reclaimed.

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```
1  // Fig. 8.20: Employee.java
2  // Employee class definition.
3  public class Employee extends Object {
4     private String firstName;
5     private String lastName;
6     private static int count;  // number of objects in memory
7
8     // initialize employee, add 1 to static count and
9     // output String indicating that constructor was called
10    public Employee( String first, String last )
11    {
12       firstName = first;
13       lastName = last;
14
15       ++count;  // increment static count of employees
16       System.out.println( "Employee object constructor: " +
17          firstName + " " + lastName );
18    }
19
20    // subtract 1 from static count when garbage collector
21    // calls finalize to clean up object and output String
22    // indicating that finalize was called
23    protected void finalize()
24    {
25       --count;  // decrement static count of employees
26       System.out.println( "Employee object finalizer: " +
27          firstName + " " + lastName + "; count = " + count );
28    }
29
30    // get first name
31    public String getFirstName()
32    {
33       return firstName;
34    }
35
36    // get last name
37    public String getLastName()
38    {
39       return lastName;
40    }
41
42    // static method to get static count value
43    public static int getCount()
44    {
45       return count;
46    }
47
48 }  // end class Employee
```

Fig. 8.20 **Employee** class that uses a **static** class variable to maintain a count of the number of **Employee** objects in memory.

When objects of class **Employee** exist, member **count** can be used in any method of an **Employee** object—in this example, **count** is incremented (line 15) by the con-

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structor and decremented (line 25) by the finalizer. When no objects of class **Employee** exist, member **count** can still be referenced, but only through a call to **public static** method **getCount** (lines 43–46), as in:

```
Employee.getCount()
```

which determines the number of **Employee** objects currently in memory. Note that when there are no objects instantiated in the program, the **Employee.getCount()** method call is issued. However, when there are objects instantiated, method **getCount** can also be called through a reference to one of the objects, as in

```
e1.getCount()
```

Good Programming Practice 8.11

*Always invoke **static** methods by using the class name and the dot operator (.). This emphasizes to other programmers reading your code that the method being called is a **static** method.*

Notice that the **Employee** class has a **finalize** method (lines 23–28). This method is included to show when it is called by the garbage collector in a program. Method **finalize** normally is declared ***protected*** so it is not part of the **public** services of a class. We will discuss the **protected** access modifier in detail in Chapter 9.

Method **main** of the **EmployeeTest** application class (Fig. 8.21) instantiates two **Employee** objects (lines 16–17). When each **Employee** object's constructor is invoked, lines 12–13 of Fig. 8.20 store references to that **Employee**'s first name and last name **String** objects. Note that these two statements *do not* make copies of the original **String**s arguments. Actually, **String** objects in Java are *immutable*—they cannot be modified after they are created (class **String** does not provide any *set* methods). Because a reference cannot be used to modify a **String**, it is safe to have many references to one **String** object in a Java program. This is not normally the case for most other classes in Java. If Java String objects are immutable, why are we able to use the + and += operators to concatenate Strings? As we discuss in Chapter 10, Strings and Characters, the **String** concatenation operations actually result in the creation of new **String** objects containing the concatenated values. The original **String** objects actually are not modified.

When **main** is done with the two **Employee** objects, the references **e1** and **e2** are set to **null** at lines 37–38. At this point references **e1** and **e2** no longer refer to the objects that were instantiated on lines 16–17. This *marks the objects for garbage collection* because there are no more references to the objects in the program.

```
1  // Fig. 8.21: EmployeeTest.java
2  // Test Employee class with static class variable,
3  // static class method, and dynamic memory.
4  import javax.swing.*;
5
```

Fig. 8.21 Using a **static** class variable to maintain a count of the number of objects of a class (part 1 of 3).

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```
 6  public class EmployeeTest {
 7
 8     // test class Employee
 9     public static void main( String args[] )
10     {
11        // prove that count is 0 before creating Employees
12        String output = "Employees before instantiation: " +
13           Employee.getCount();
14
15        // create two Employees; count should be 2
16        Employee e1 = new Employee( "Susan", "Baker" );
17        Employee e2 = new Employee( "Bob", "Jones" );
18
19        // Prove that count is 2 after creating two Employees.
20        // Note: static methods should be called only via the
21        // class name for the class in which they are defined.
22        output += "\n\nEmployees after instantiation: " +
23           "\nvia e1.getCount(): " + e1.getCount() +
24           "\nvia e2.getCount(): " + e2.getCount() +
25           "\nvia Employee.getCount(): " + Employee.getCount();
26
27        // get names of Employees
28        output += "\n\nEmployee 1: " + e1.getFirstName() +
29           " " + e1.getLastName() + "\nEmployee 2: " +
30           e2.getFirstName() + " " + e2.getLastName();
31
32        // If there is only one reference to each employee (as
33        // on this example), the following statements mark
34        // those objects for garbage collection. Otherwise,
35        // these statement simply decrement the reference count
36        // for each object.
37        e1 = null;
38        e2 = null;
39
40        System.gc(); // suggest call to garbage collector
41
42        // Show Employee count after calling garbage collector.
43        // Count displayed may be 0, 1 or 2 depending on
44        // whether garbage collector executed immediately and
45        // number of Employee objects it collects.
46        output += "\n\nEmployees after System.gc(): " +
47           Employee.getCount();
48
49        JOptionPane.showMessageDialog( null, output,
50           "Static Members and Garbage Collection",
51           JOptionPane.INFORMATION_MESSAGE );
52
53        System.exit( 0 );
54     }
55
56  }  // end class EmployeeTest
```

Fig. 8.21 Using a **`static`** class variable to maintain a count of the number of objects of a class (part 2 of 3).

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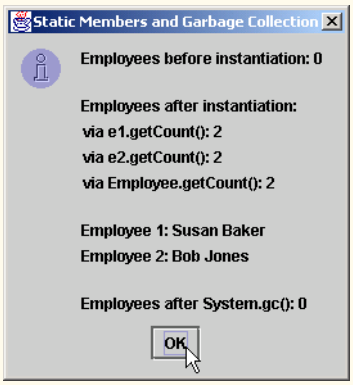


```
Employee object constructor: Susan Baker
Employee object constructor: Bob Jones
Employee object finalizer: Susan Baker; count = 1
Employee object finalizer: Bob Jones; count = 0
```

Fig. 8.21 Using a **static** class variable to maintain a count of the number of objects of a class (part 3 of 3).

Eventually, the garbage collector reclaims the memory for these objects (or the memory is reclaimed by the operating system when the program terminates). Because it is not guaranteed when the garbage collector will execute, we make an explicit call to the garbage collector with line 40, which uses **public static** method **gc** from class **System** (**java.lang** package) to indicate that the garbage collector immediately should make a best effort attempt to collect objects that have been marked for garbage collection. However, this is just a best effort—it is possible that no objects or a subset of the garbage objects will be collected. In our example, the garbage collector did execute before lines 49–51 displayed the results of the program. The last line of the output indicates that the number of **Employee** objects in memory is 0 after the call to **System.gc()**. Also, the last two lines of the command window output show that the **Employee** object for **Susan Baker** was finalized before the **Employee** object for **Bob Jones**. Remember, the garbage collector is not guaranteed to execute when **System.gc()** is invoked nor is it guaranteed to collect objects in a specific order, so it is possible that the output of this program on your system may differ.

[*Note*: A method declared **static** cannot access non**static** class members. Unlike non**static** methods, a **static** method has no **this** reference because, **static** class variables and **static** class methods exist independent of any objects of a class and before any objects of the class have been instantiated.]

Common Programming Error 8.12

*Referring to the **this** reference in a **static** method is a syntax error.*

Common Programming Error 8.13

*It is a syntax error for a **static** method to call an instance method or to access an instance variable.*

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Software Engineering Observation 8.21

Any **`static`** *class variables and* **`static`** *class methods exist and can be used even if no objects of that class have been instantiated.*

8.16 Data Abstraction and Encapsulation

Classes normally hide their implementation details from the clients of the classes. This is called *encapsulation* or *information hiding*. As an example of encapsulation, let us consider a data structure called a *stack*.

Think of a stack in terms of a pile of dishes. When a dish is placed on the pile, it is always placed at the top (referred to as *pushing* the dish onto the stack), and when a dish is removed from the pile, it is always removed from the top (referred to as *popping* the dish off the stack). Stacks are known as *last-in, first-out (LIFO) data structures*—the last item pushed (inserted) on the stack is the first item popped (removed) from the stack.

The programmer can create a stack class and hide from its clients implementation of the stack. Stacks can easily be implemented with arrays and other methods (such as linked lists; see Chapter 19, "Data Structures," and Chapter 20, "Java Utilities Packages and Bit Manipulation"). A client of a stack class need not know how the stack is implemented. The client simply requires that when data items are placed in the stack, they will be recalled in last-in, first-out order. This concept is referred to as *data abstraction,* and Java classes define abstract data types (ADTs). Although users might happen to know the details of how a class is implemented, users may not write code that depends on these details. This means that a particular class (such as one that implements a stack and its operations of *push* and *pop*) can be replaced with another version without affecting the rest of the system, as long as the public services of that class does not change (i.e., every method still has the same name, return type and parameter list in the new class definition).

The job of a high-level language is to create a view convenient for programmers to use. There is no single accepted standard view—that is one reason why there are so many programming languages. Object-oriented programming in Java presents yet another view.

Most programming languages emphasize actions. In these languages, data exists in support of the actions programs need to take. Data is "less interesting" than actions, anyway. Data is "crude." There are only a few built-in data types, and it is difficult for programmers to create their own new data types.

This view changes with Java and the object-oriented style of programming. Java elevates the importance of data. The primary activity in Java is creating new data types (i.e., classes) and expressing the interactions among objects of those data types.

To move in this direction, the programming-languages community needed to formalize some notions about data. The formalization we consider is the notion of *abstract data types (ADTs).* ADTs receive as much attention today as structured programming did over the last two decades. ADTs do not replace structured programming. Rather, they provide an additional formalization to further improve the program development process.

What is an abstract data type? Consider the built-in type **`int`**. What comes to mind is the notion of an integer in mathematics, but **`int`** on a computer is not precisely what an integer is in mathematics. In particular, computer **`int`**s are normally quite limited in size. For example, **`int`** on a 32-bit machine is limited approximately to the range –2 billion to +2 billion. If the result of a calculation falls outside this range, an error occurs and the

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machine responds in some machine-dependent manner, including the possibility of "quietly" producing an incorrect result. Mathematical integers do not have this problem. So the notion of a computer **int** is really only an approximation to the notion of a real-world integer. The same is true with **float**.

The point is that even the built-in data types provided with programming languages like Java are really only approximations or models of real-world concepts and behaviors. We have taken **int** for granted until this point, but now you have a new perspective to consider. Types like **int**, **float**, **char** and others are all examples of abstract data types. They are essentially ways of representing real-world notions to some satisfactory level of precision within a computer system.

An abstract data type actually captures two notions, namely a *data representation* and the *operations* that are allowed on that data. For example, the notion of **int** defines addition, subtraction, multiplication, division and modulus operations in Java, but division by zero is undefined. Another example is the notion of negative integers whose operations and data representation are clear, but the operation of taking the square root of a negative integer is undefined. In Java, the programmer uses classes to implement abstract data types.

Java has a small set of primitive types. ADTs extend the base programming language.

Software Engineering Observation 8.22

The programmer is able to create new types through the use of the class mechanism. These new types can be designed to be used as conveniently as the built-in types. Thus, Java is an extensible language. Although the language is easy to extend with these new types, the base language itself is not changeable.

New Java classes can be proprietary to an individual, to small groups, to companies, and so on. Many classes are placed in standard *class libraries* intended for wide distribution. This does not necessarily promote standards, although de facto standards are emerging. The full value of Java will be realized only when substantial, standardized class libraries become more widely available than they are today. In the United States, such standardization often happens through *ANSI*, the *American National Standards Institute*. Worldwide standardization often happens through *ISO, the International Standards Organization*. Regardless of how these libraries ultimately appear, the reader who learns Java and object-oriented programming will be ready to take advantage of the new kinds of rapid, component-oriented software development made possible with class libraries.

8.16.1 Example: Queue Abstract Data Type

Each of us stands in line from time to time. A waiting line is also called a *queue.* We wait in line at the supermarket checkout counter, we wait in line to get gasoline, we wait in line to board a bus, we wait in line to pay a toll on the highway, and students know all too well about waiting in line during registration to get the courses they want. Computer systems use many waiting lines internally, so we write programs that simulate what queues are and do.

A queue is a good example of an abstract data type. A queue offers well-understood behavior to its clients. Clients put things in a queue one at a time—using an *enqueue* operation, and the clients get those things back one at a time on demand—using a *dequeue* operation. Conceptually, a queue can become infinitely long. A real queue, of course, is finite. Items are returned from a queue in *first-in, first-out (FIFO)* order—the first item inserted in the queue is the first item removed from the queue.

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The queue hides an internal data representation that keeps track of the items currently waiting in line, and it offers a set of operations to its clients, namely *enqueue* and *dequeue*. The clients are not concerned about implementation of the queue. Clients merely want the queue to operate "as advertised." When a client enqueues a new item, the queue should accept that item and place it internally in some kind of first-in, first-out data structure. When the client wants the next item from the front of the queue, the queue should remove the item from its internal representation and should deliver the item to the outside world in FIFO order (i.e., the item that has been in the queue the longest should be the next one returned by the next *dequeue* operation).

The queue ADT guarantees the integrity of its internal data structure. Clients must not manipulate this data structure directly. Only the queue ADT has access to its internal data (i.e., the queue ADT encapsulates its data). Clients must cause only allowable operations to be performed on the data representation; operations not provided in the ADT's public interface are rejected by the ADT in some appropriate manner. This could mean issuing an error message, terminating execution, or simply ignoring the operation request.

8.17 (Optional Case Study) Thinking About Objects: Starting to Program the Classes for the Elevator Simulation

In the "Thinking About Objects" sections in Chapters 1 through 7, we introduced the fundamentals of object orientation and developed an object-oriented design for our elevator simulation. In Chapter 8, we introduced the details of programming with Java classes. We now begin implementing our object-oriented design in Java. At the end of this section, we show how to generate code in Java, working from class diagrams. This process is referred to as *forward engineering*.[1]

Visibility

Before we begin implementing our design in Java, we apply *member-access modifiers* (see Section 8.2) to the members of our classes. In Chapter 8, we introduced the access specifiers **`public`** and **`private`**—these determine the *visibilities* of an object's attributes and methods to other objects. Before we create class files, we consider which attributes and methods of our classes should be **`public`** and which should be **`private`**.

Software Engineering Observation 8.23

Each element of a class should have **`private`** *visibility unless it can be proven that the element needs* **`public`** *visibility.*

In Chapter 8, we discussed how attributes generally should be **`private`**, but what about the operations of a class—its methods? These operations are invoked by clients of that class; therefore, the methods normally should be **`public`**. In the UML, **`public`** visibility is indicated by placing a plus sign (+) before a particular element (i.e., a method or an attribute); a minus sign (-) indicates **`private`** visibility. Figure 8.13 shows our updated class diagram with visibility notations included.

1. G. Booch, *The Unified Modeling Language User Guide*. Massachusetts: Addison Wesley Longman, Inc., 1999: 16. [Once code exists, the process of going backward from the code to reproduce design documents is called *reverse engineering*.]

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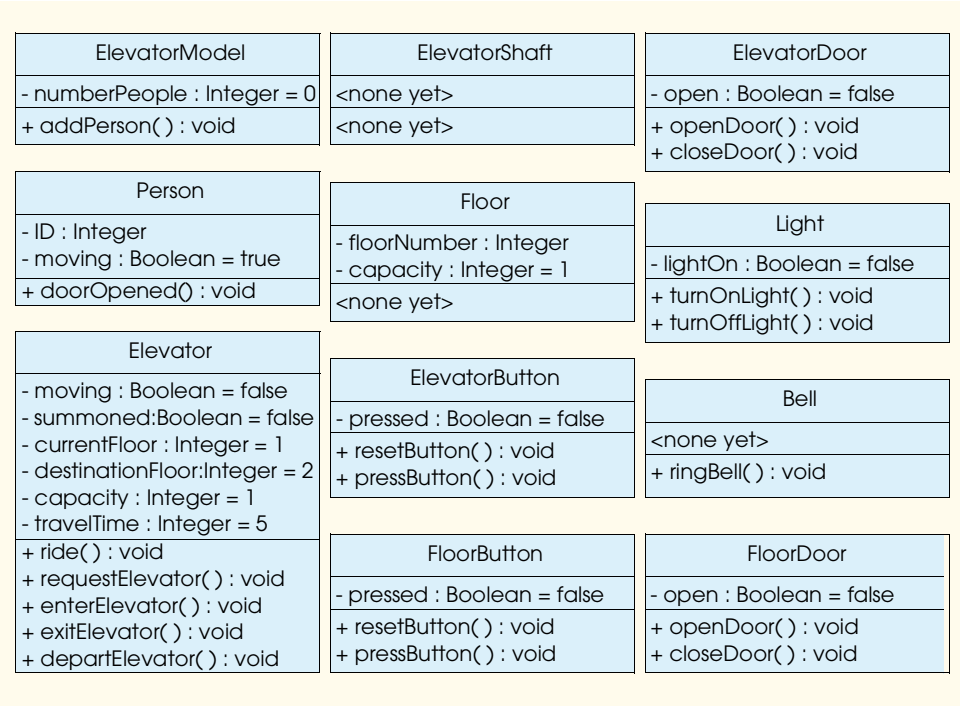

Fig. 8.13 Complete class diagram with visibility notations.

Implementation: Forward Engineering

Forward engineering is the process of transforming a design, such as that in a class diagram, into code of a specific programming language, such as Java. Now that we have discussed programming Java classes, we forward engineer the class diagram of Fig. 8.13 into the Java code for our elevator simulator. The generated code will represent only the "skeleton," or the structure, of the model.[2] In Chapters 9 and 10, we modify the code to incorporate inheritance and interfaces, respectively. In Appendix G, Appendix H and Appendix I, we present the complete, working Java code for our model.

As an example, we forward engineer class **`Elevator`** from Fig. 8.13. We use this figure to determine the attributes and operations of that class. We use the class diagram of Fig. 3.23 to determine associations (and aggregations) among classes. We adhere to the following four guidelines:

1. Use the name located in the first compartment to declare the class as a **`public`** class with an empty constructor. For example, class **`Elevator`** yields

2. So far, we have presented only about half of the case-study material—we have not yet discussed inheritance, event handling, multithreading and animation. The standard development process recommends finishing the design process before starting the coding process. Technically, we will not have finished designing our system until we have discussed these additional topics, so our current code implementation might seem premature. We present only a partial implementation illustrating the topics covered in Chapter 8.

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```
public class Elevator {

   public Elevator() {}
}
```

2. Use the attributes located in the second compartment to declare the member variables. For example, the **private** attributes **moving**, **summoned**, **currentFloor**, **destinationFloor**, **capacity** and **travelTime** of class **Elevator** yield

```
public class Elevator {

   // class attributes
   private boolean moving;
   private boolean summoned;
   private int currentFloor = 1;
   private int destinationFloor = 2;
   private int capacity = 1;
   private int travelTime = 5;

   // class constructor
   public Elevator() {}
}
```

3. Use the associations described in the class diagram to generate the references to other objects. For example, according to Fig. 3.23, **Elevator** contains one object each of classes **ElevatorDoor**, **ElevatorButton** and **Bell**. This yields

```
public class Elevator {

   // class attributes
   private boolean moving;
   private boolean summoned;
   private int currentFloor = 1;
   private int destinationFloor = 2;
   private int capacity = 1;
   private int travelTime = 5;

   // class objects
   private ElevatorDoor elevatorDoor;
   private ElevatorButton elevatorButton;
   private Bell bell;

   // class constructor
   public Elevator() {}
}
```

4. Use the operations located in the third compartment of Fig. 8.13 to declare the methods. For example, the **public** operations **ride**, **requestElevator**, **enterElevator**, **exitElevator** and **departElevator** in **Elevator** yield

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```
public class Elevator {

   // class attributes
   private boolean moving;
   private boolean summoned;
   private int currentFloor = 1;
   private int destinationFloor = 2;
   private int capacity = 1;
   private int travelTime = 5;

   // class objects
   private ElevatorDoor elevatorDoor;
   private ElevatorButton elevatorButton;
   private Bell bell;

   // class constructor
   public Elevator() {}

   // class methods
   public void ride() {}
   public void requestElevator() {}
   public void enterElevator() {}
   public void exitElevator() {}
   public void departElevator() {}
}
```

This concludes the basics of forward engineering. We return to this example at the ends of "Thinking About Objects" Section 9.23 and Section 10.22 to incorporate inheritance, interfaces and event handling.

SUMMARY

- OOP encapsulates data (attributes) and methods (behaviors) into objects; the data and methods of an object are intimately tied together.
- Objects have the property of information hiding. Objects might know how to communicate with one another across well-defined interfaces, but they normally are not allowed to know how other objects are implemented.
- Java programmers concentrate on creating their own user-defined types called classes.
- The non-**static** data components of a class are called instance variables. The **static** data components of a class are called class variables.
- Java uses inheritance to create new classes from existing class definitions.
- Every class in Java is a subclass of **Object**. Thus, every new class definition has the attributes (data) and behaviors (methods) of class **Object**.
- Keywords **public** and **private** are member access modifiers.
- Instance variables and methods declared with member access modifier **public** are accessible wherever the program has a reference to an object of the class in which they are defined.
- Instance variables and methods declared with member access modifier **private** are accessible only to methods of the class in which they are defined.
- Instance variables are normally declared **private** and methods are normally declared **public**.
- The **public** methods (or **public** services) of a class are used by clients of the class to manipulate the data stored in objects of the class.

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- A constructor is a method with the exact same name as the class that initializes the instance variables of an object of the class when the object is instantiated. Constructor methods can be overloaded for a class. Constructors can take arguments but cannot specify a return value type.
- Constructors and other methods that change instance variable values should always maintain objects in a consistent state.
- Method **`toString`** takes no arguments and returns a **`String`**. The original **`toString`** method of class **`Object`** is a placeholder that is normally redefined by a subclass.
- When an object is instantiated, operator **`new`** allocates the memory for the object, then **`new`** calls the constructor for the class to initialize the instance variables of the object.
- If the **`.class`** files for the classes used in a program are in the same directory as the class that uses them, **`import`** statements are not required.
- Concatenating a **`String`** and any object results in an implicit call to the object's **`toString`** method to convert the object to a **`String`**, then the **`String`**s are concatenated.
- Within a class's scope, class members are accessible to all of that class's methods and can be referenced simply by name. Outside a class's scope, class members can only be accessed off a "handle" (i.e., a reference to an object of the class).
- If a method defines a variable with the same name as a variable with class scope, the class-scope variable is hidden by the method-scope variable in the method. A hidden instance variable can be accessed in the method by preceding its name with the keyword **`this`** and the dot operator.
- Each class and interface in the Java API belongs to a specific package that contains a group of related classes and interfaces.
- Packages are actually directory structures used to organize classes and interfaces. Packages provide a mechanism for software reuse and a convention for unique class names.
- Creating a reusable class requires: defining a **`public`** class, adding a **`package`** statement to the class definition file, compiling the class into the appropriate package directory structure and importing the class into a program.
- When compiling a class in a package, the option **`-d`** must be passed to the compiler to specify where to create (or locate) all the directories in the **`package`** statement.
- The **`package`** directory names become part of the class name when the class is compiled. Use this fully qualified name in programs or **`import`** the class and use its short name (the name of the class by itself) in the program.
- If no constructors are defined for a class, the compiler creates a default constructor.
- When one object of a class has a reference to another object of the same class, the first object can access all the second object's data and methods.
- Classes often provide **`public`** methods to allow clients of the class to *set* (i.e., assign values to) or *get* (i.e., obtain the values of) **`private`** instance variables. *Get* methods are also commonly called accessor methods or query methods. *Set* methods are also commonly called mutator methods (because they typically change a value).
- Every event has a source—the GUI component with which the user interacted to signal the program to do a task.
- Use the keyword **`final`** to specify that a variable is not modifiable and that any attempt to modify the variable is an error. A **`final`** variable cannot be modified by assignment after it is initialized. Such a variable must be initialized in its declaration or in every constructor of the class.
- With composition, a class has references to objects of other classes as members.
- When no member access modifier is provided for a method or variable when it is defined in a class, the method or variable is considered to have package access.

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- If a program uses multiple classes from the same package, these classes can access each other's package-access methods and data directly through a reference to an object.
- Each object has access to a reference to itself called the **`this`** reference that can be used inside the methods of the class to refer to the object's data and other methods explicitly.
- Any time you have a reference in a program (even as the result of a method call), the reference can be followed by a dot operator and a call to one of the methods for the reference type.
- Java performs automatic garbage collection of memory. When an object is no longer used in the program (i.e., there are no references to the object), the object is marked for garbage collection.
- Every class in Java can have a finalizer method that returns resources to the system. A class's finalizer method always has the name **`finalize`**, receives no parameters and returns no value. Method **`finalize`** is originally defined in class **`Object`** as a placeholder that does nothing. This guarantees that every class has a **`finalize`** method for the garbage collector to call.
- A **`static`** class variable represents class-wide information—all objects of the class share the same piece of data. A class's **`public static`** members can be accessed through a reference to any object of that class, or they can be accessed through the class name using the dot operator.
- **`public static`** method **`gc`** from class **`System`** suggests that the garbage collector immediately make a best effort attempt to collect garbage objects.The garbage collector is not guaranteed to collect objects in a specific order.
- A method declared **`static`** cannot access non**`static`** class members. Unlike non**`static`** methods, a **`static`** method has no **`this`** reference, because **`static`** class variables and **`static`** class methods exist independent of any objects of a class.
- **`static`** class members exist even when no objects of that class exist—they are available as soon as the class is loaded into memory at execution time.

TERMINOLOGY

abstract data type (ADT)
access method
aggregation
attribute
behavior
cascaded method calls
class
class definition
class library
class method (**`static`**)
class scope
class variable
client of a class
composition
concatenated method calls
consistent state for an instance variable
constructor
container class
`-d` compiler option
data type
default constructor
dot operator (**`.`**)
encapsulation
extends
extensibility
finalizer
get method
helper method
implementation of a class
information hiding
initialize a class object
instance method
instance of a class
instance variable
instantiate an object of a class
interface to a class
member access control
member access modifiers
member access operator (**`.`**)
message
method
method calls
mutator method
`new` operator
no-argument constructor
object

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object-based programming (OBP)
object-oriented programming (OOP)
package access
package statement
predicate method
principle of least privilege
private
programmer-defined type
public
public interface of a class
query method
rapid applications development (RAD)
reusable code
services of a class
set method
software reusability
static class variable
static method
this reference
user-defined type
utility method

SELF-REVIEW EXERCISES

8.1 Fill in the blanks in each of the following statements:

a) Class members are accessed via the _____ operator in conjunction with a reference to an object of the class.
b) Members of a class specified as _____ are accessible only to methods of the class.
c) A _____ is a special method used to initialize the instance variables of a class.
d) A _____ method is used to assign values to **private** instance variables of a class.
e) Methods of a class are normally made _____ and instance variables of a class are normally made _____.
f) A _____ method is used to retrieve values of **private** data of a class.
g) The keyword _____ introduces a class definition.
h) Members of a class specified as _____ are accessible anywhere an object of the class is in scope.
i) The _____ operator dynamically allocates memory for an object of a specified type and returns a _____ to that type.
j) A _____ instance variable represents class-wide information.
k) The keyword _____ specifies that an object or variable is not modifiable after it is initialized.
l) A method declared **static** cannot access _____ class members.

ANSWERS TO SELF-REVIEW EXERCISES

8.1 a) dot (**.**). b) **private**. c) constructor. d) set. e) **public**, **private**. f) get. g) **class**. h) **public**. i) **new**, reference. j) **static**. k) **final**. l) non**static**.

EXERCISES

8.2 Create a class called **Complex** for performing arithmetic with complex numbers. Write a driver program to test your class.

Complex numbers have the form

```
realPart + imaginaryPart * i
```

where *i* is

$$\sqrt{-1}$$

Use floating-point variables to represent the **private** data of the class. Provide a constructor method that enables an object of this class to be initialized when it is declared. Provide a no-argu-

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ment constructor with default values in case no initializers are provided. Provide **public** methods for each of the following:

a) Addition of two **Complex** numbers: The real parts are added together and the imaginary parts are added together.
b) Subtraction of two **Complex** numbers: The real part of the right operand is subtracted from the real part of the left operand and the imaginary part of the right operand is subtracted from the imaginary part of the left operand.
c) Printing **Complex** numbers in the form **(a, b)**, where **a** is the real part and **b** is the imaginary part.

8.3 Create a class called **Rational** for performing arithmetic with fractions. Write a driver program to test your class.

Use integer variables to represent the **private** instance variables of the class—the **numerator** and the **denominator**. Provide a constructor method that enables an object of this class to be initialized when it is declared. The constructor should store the fraction in reduced form (i.e., the fraction

```
2/4
```

would be stored in the object as 1 in the **numerator** and 2 in the **denominator**). Provide a no-argument constructor with default values in case no initializers are provided. Provide **public** methods for each of the following:

a) Addition of two **Rational** numbers. The result of the addition should be stored in reduced form.
b) Subtraction of two **Rational** numbers. The result of the subtraction should be stored in reduced form.
c) Multiplication of two **Rational** numbers. The result of the multiplication should be stored in reduced form.
d) Division of two **Rational** numbers. The result of the division should be stored in reduced form.
e) Printing **Rational** numbers in the form **a/b**, where **a** is the **numerator** and **b** is the **denominator**.
f) Printing **Rational** numbers in floating-point format. (Consider providing formatting capabilities that enable the user of the class to specify the number of digits of precision to the right of the decimal point.)

8.4 Modify the **Time3** class of Fig. 8.8 to include the **tick** method that increments the time stored in a **Time3** object by one second. Also provide method **incrementMinute** to increment the minute and method **incrementHour** to increment the hour. The **Time3** object should always remain in a consistent state. Write a driver program that tests the **tick** method, the **incrementMinute** method and the **incrementHour** method to ensure that they work correctly. Be sure to test the following cases:

a) incrementing into the next minute.
b) incrementing into the next hour.
c) incrementing into the next day (i.e., 11:59:59 PM to 12:00:00 AM).

8.5 Modify the **Date** class of Fig. 8.13 to perform error-checking on the initializer values for instance variables **month**, **day** and **year** (currently it validates only the month and day). Also, provide a method **nextDay** to increment the day by one. The **Date** object should always remain in a consistent state. Write a driver program that tests the **nextDay** method in a loop that prints the date during each iteration of the loop to illustrate that the **nextDay** method works correctly. Be sure to test the following cases:

a) incrementing into the next month.
b) incrementing into the next year.

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8.6 Combine the modified **Time3** class of Exercise 8.5 and the modified **Date** class of Exercise 8.5 into one class called **DateAndTime**. Modify the **tick** method to call the **nextDay** method if the time is incremented into the next day. Modify methods **toString** and **toUniversalString()** to output the date in addition to the time. Write a driver program to test the new class **DateAndTime**. Specifically test incrementing the time to the next day.

8.7 Modify the set methods in class **Time3** of Fig. 8.8 to return appropriate error values if an attempt is made to set one of the instance variables **hour**, **minute** or **second** of an object of class **Time** to an invalid value. (*Hint*: Use **boolean** return types on each method.)

8.8 Create a class **Rectangle**. The class has attributes **length** and **width**, each of which defaults to 1. It has methods that calculate the **perimeter** and the **area** of the rectangle. It has *set* and *get* methods for both **length** and **width**. The *set* methods should verify that **length** and **width** are each floating-point numbers larger than 0.0 and less than 20.0. Write a program to test class **Rectangle**.

8.9 Create a more sophisticated **Rectangle** class than the one you created in Exercise 8.8. This class stores only the Cartesian coordinates of the four corners of the rectangle. The constructor calls a *set* method that accepts four sets of coordinates and verifies that each of these is in the first quadrant with no single *x*- or *y*-coordinate larger than 20.0. The *set* method also verifies that the supplied coordinates do, in fact, specify a rectangle. Provide methods to calculate the **length**, **width**, **perimeter** and **area**. The length is the larger of the two dimensions. Include a predicate method **isSquare** which determines whether the rectangle is a square. Write a program to test class **Rectangle**.

8.10 Modify the **Rectangle** class of Exercise 8.9 to include a **draw** method that displays the rectangle inside a 25-by-25 box enclosing the portion of the first quadrant in which the rectangle resides. Use the methods of the **Graphics** class to help output the **Rectangle**. If you feel ambitious, you might include methods to scale the size of the rectangle, rotate it and move it around within the designated portion of the first quadrant.

8.11 Create a class **HugeInteger** which uses a 40-element array of digits to store integers as large as 40 digits each. Provide methods **inputHugeInteger**, **outputHugeInteger**, **addHugeIntegers** and **substractHugeIntegers**. For comparing **HugeInteger** objects, provide methods **isEqualTo**, **isNotEqualTo**, **isGreaterThan**, **isLessThan**, **IsGreaterThanOrEqualTo** and **isLessThanOrEqualTo**—each of these is a "predicate" method that simply returns **true** if the relationship holds between the two **HugeInteger**s and returns **false** if the relationship does not hold. Provide a predicate method **isZero**. If you feel ambitious, also provide the method **multiplyHugeIntegers**, the method **divideHugeIntegers** and the method **modulusHugeIntegers.**

8.12 Create a class **TicTacToe** that will enable you to write a complete program to play the game of Tic-Tac-Toe. The class contains as private data a 3-by-3 double array of integers. The constructor should initialize the empty board to all zeros. Allow two human players. Wherever the first player moves, place a 1 in the specified square; place a 2 wherever the second player moves. Each move must be to an empty square. After each move determine whether the game has been won and whether the game is a draw. If you feel ambitious, modify your program so that the computer makes the moves for one of the players automatically. Also, allow the player to specify whether he or she wants to go first or second. If you feel exceptionally ambitious, develop a program that will play three-dimensional Tic-Tac-Toe on a 4-by-4-by-4 board [Note: This is a challenging project that could take many weeks of effort!].

8.13 Explain the notion of package access in Java. Explain the negative aspects of package access as described in the text.

8.14 What happens when a return type, even **void**, is specified for a constructor?

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8.15 Create a **Date** class with the following capabilities:

a) Output the date in multiple formats such as

```
MM/DD/YYYY
June 14, 1992
DDD YYYY
```

b) Use overloaded constructors to create **Date** objects initialized with dates of the formats in part a).

[Hint: You can compare **String**s using method equals. Suppose you have two **String** references **s1** and **s2**, if those **String**s are equal, **s1.equals(s2)** returns **true**; otherwise, it returns **false**.]

8.16 Create class **SavingsAccount**. Use a **static** class variable to store the **annualInterestRate** for all account holders. Each object of the class contains a **private** instance variable **savingsBalance** indicating the amount the saver currently has on deposit. Provide method **calculateMonthlyInterest** to calculate the monthly interest by multiplying the **savingsBalance** by **annualInterestRate** divided by 12; this interest should be added to **savingsBalance**. Provide a **static** method **modifyInterestRate** that sets the **annualInterestRate** to a new value. Write a driver program to test class **SavingsAccount**. Instantiate two **savingsAccount** objects, **saver1** and **saver2**, with balances of $2000.00 and $3000.00, respectively. Set **annualInterestRate** to 4%, then calculate the monthly interest and print the new balances for each of the savers. Then set the **annualInterestRate** to 5% and calculate the next month's interest and print the new balances for each of the savers.

8.17 Create class **IntegerSet**. Each object of the class can hold integers in the range 0 through 100. A set is represented internally as an array of **boolean**s. Array element **a[i]** is **true** if integer *i* is in the set. Array element **a[j]** is **false** if integer *j* is not in the set. The no-argument constructor initializes a set to the so-called "empty set" (i.e., a set whose array representation contains all **false** values).

Provide the following methods: Method **unionOfIntegerSets** creates a third set which is the set-theoretic union of two existing sets (i.e., an element of the third set's array is set to **true** if that element is **true** in either or both of the existing sets; otherwise, the element of the third set is set to **false**). Method **intersectionOfIntegerSets** creates a third set which is the set-theoretic intersection of two existing sets i.e., an element of the third set's array is set to **false** if that element is **false** in either or both of the existing sets; otherwise, the element of the third set is set to **true**). Method **insertElement** inserts a new integer *k* into a set (by setting **a[k]** to **true**). Method **deleteElement** deletes integer *m* (by setting **a[m]** to **false**). Method **setPrint** prints a set as a list of numbers separated by spaces. Print only those elements that are present in the set. Print **---** for an empty set. Method **isEqualTo** determines if two sets are equal. Write a program to test your **IntegerSet** class. Instantiate several **IntegerSet** objects. Test that all your methods work properly.

8.18 It would be perfectly reasonable for the **Time1** class of Figure 8.1 to represent the time internally as the number of seconds since midnight rather than the three integer values **hour**, **minute** and **second**. Clients could use the same **public** methods and get the same results. Modify the **Time1** class of Figure 8.1 to implement the **Time1** as the number of seconds since midnight and show that there is no change visible to the clients of the class.

8.19 *(Drawing Program)* Create a drawing applet that randomly draws lines, rectangles and ovals. For this purpose, create a set of "smart" shape classes where objects of these classes know how to draw themselves if provided with a **Graphics** object that tells them where to draw (i.e., the applet's **Graphics** object allows a shape to draw on the applet's background). The class names should be **MyLine**, **MyRect** and **MyOval**.

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The data for class **MyLine** should include *x1*, *y1*, *x2* and *y2* coordinates. Method **drawLine** method of class **Graphics** will connect the two points supplied with a line. The data for classes **MyRect** and **MyOval** should include an upper-left *x*-coordinate value, an upper-left *y*-coordinate value, a *width* (must be nonnegative) and a *height* (must be nonnegative). All data in each class must be **private**.

In addition to the data, each class should define at least the following **public** methods:

a) A constructor with no arguments that sets the coordinates to 0.
b) A constructor with arguments that sets the coordinates to the supplied values.
c) Set methods for each individual piece of data that allow the programmer to independently set any piece of data in a shape (e.g., if you have an instance variable **x1**, you should have a method **setX1**).
d) Get methods for each individual piece of data that allow the programmer to independently retrieve any piece of data in a shape (e.g., if you have an instance variable **x1**, you should have a method **getX1**).
e) A **draw** method with the first line

```
public void draw( Graphics g )
```

will be called from the applet's **paint** method to draw a shape onto the screen.

The preceding methods are required. If you would like to provide more methods for flexibility, please do so.

Begin by defining class **MyLine** and an applet to test your classes. The applet should have a **MyLine** instance variable **line** that can refer to one **MyLine** object (created in the applet's **init** method with random coordinates). The applet's **paint** method should draw the shape with a statement like

```
line.draw( g );
```

where **line** is the **MyLine** reference and **g** is the **Graphics** object that the shape will use to draw itself on the applet.

Next, change the single **MyLine** reference into an array of **MyLine** references and hard code several **MyLine** objects into the program for drawing. The applet's **paint** method should walk through the array of **MyLine** objects and draw every one.

After the preceding part is working, you should define the **MyOval** and **MyRect** classes and add objects of these classes into the **MyRect** and **MyOval** arrays. The applet's **paint** method should walk through each array and draw every shape. Create five shapes of each type.

Once the applet is running, select **Reload** from the **appletviewer**'s **Applet** menu to reload the applet. This will cause the applet to choose new random numbers for the shapes and draw the shapes again.

In Chapter 9, we will modify this exercise to take advantage of the similarities between the classes and to avoid reinventing the wheel.

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Object-Oriented Programming

Objectives

- To understand inheritance and software reusability.
- To understand superclasses and subclasses.
- To appreciate how polymorphism makes systems extensible and maintainable.
- To understand the distinction between abstract classes and concrete classes.
- To learn how to create abstract classes and interfaces.

Say not you know another entirely, till you have divided an inheritance with him.
Johann Kasper Lavater

This method is to define as the number of a class the class of all classes similar to the given class.
Bertrand Russell

Good as it is to inherit a library, it is better to collect one.
Augustine Birrell

General propositions do not decide concrete cases.
Oliver Wendell Holmes

A philosopher of imposing stature doesn't think in a vacuum. Even his most abstract ideas are, to some extent, conditioned by what is or is not known in the time when he lives.
Alfred North Whitehead

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Outline

9.1 Introduction
9.2 Superclasses and Subclasses
9.3 `protected` Members
9.4 Relationship between Superclass Objects and Subclass Objects
9.5 Constructors and Finalizers in Subclasses
9.6 Implicit Subclass-Object-to-Superclass-Object Conversion
9.7 Software Engineering with Inheritance
9.8 Composition vs. Inheritance
9.9 Case Study: Point, Circle, Cylinder
9.10 Introduction to Polymorphism
9.11 Type Fields and `switch` Statements
9.12 Dynamic Method Binding
9.13 `final` Methods and Classes
9.14 Abstract Superclasses and Concrete Classes
9.15 Polymorphism Examples
9.16 Case Study: A Payroll System Using Polymorphism
9.17 New Classes and Dynamic Binding
9.18 Case Study: Inheriting Interface and Implementation
9.19 Case Study: Creating and Using Interfaces
9.20 Inner Class Definitions
9.21 Notes on Inner Class Definitions
9.22 Type-Wrapper Classes for Primitive Types
9.23 (Optional Case Study) Thinking About Objects: Incorporating Inheritance into the Elevator Simulation
9.24 (Optional) Discovering Design Patterns: Introducing Creational, Structural and Behavioral Design Patterns

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

9.1 Introduction

In this chapter, we discuss object-oriented programming (OOP) and its key component technologies—*inheritance* and *polymorphism.* Inheritance is a form of software reusability in which new classes are created from existing classes by absorbing their attributes and behaviors and adding new capabilities the new classes require. Inheritance takes advantage of *class* relationships where objects of a certain class—such as a class of vehicles—have the same characteristics. Newly created classes of objects are derived by absorbing characteristics of existing classes and adding unique characteristics of their own. An object of class "convertible" certainly has the characteristics of the more general class "automobile," but a convertible's roof goes up and down.

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Software reusability saves time in program development. It encourages reuse of proven and debugged high-quality software, thus reducing problems after a system becomes operational. These are exciting possibilities. Polymorphism enables us to write programs in a general fashion to handle a wide variety of existing and yet-to-be-specified related classes. Polymorphism makes it easy to add new capabilities to a system. Inheritance and polymorphism are effective techniques for dealing with software complexity.

When creating a new class, instead of writing completely new instance variables and instance methods, the programmer can designate that the new class is to *inherit* the instance variables and instance methods of a previously defined *superclass.* The new class is referred to as a *subclass.* Each subclass itself becomes a candidate to be a superclass for some future subclass.

The *direct superclass* of a class is the superclass from which the class explicitly inherits (via the keyword **`extends`**). An indirect superclass is inherited from two or more levels up the class hierarchy. For example, class **`JApplet`** (package **`javax.swing`**) extends class **`Applet`** (package **`java.applet`**). Thus, each applet class we have defined is a direct subclass of **`JApplet`** and an indirect subclass of **`Applet`**.

With *single inheritance,* a class is derived from one superclass. Java does not support *multiple inheritance* (as C++ does) but it does support the notion of *interfaces.* Interfaces help Java achieve many of the advantages of multiple inheritance without the associated problems. We will discuss the details of interfaces in this chapter. We consider both general principles and a detailed specific example of creating and using interfaces.

A subclass normally adds instance variables and instance methods of its own, so a subclass is generally larger than its superclass. A subclass is more specific than its superclass and represents a smaller, more specialized group of objects. With single inheritance, the subclass starts out essentially the same as the superclass. The real strength of inheritance comes from the ability to define in the subclass additions to, or replacements for, the features inherited from the superclass.

Every subclass object is also an object of that class's superclass. For example, every applet we have defined is considered to be an object of class **`JApplet`**. Also, because **`JApplet`** extends **`Applet`**, every applet we have defined is considered to be an **`Applet`**. This information is critical when developing applets, because an applet container can execute a program only if it is an **`Applet`**. Although a subclass object always can be treated as one of its superclass types, superclass objects are not considered to be objects of their subclass types. We will take advantage of this "subclass-object-is-a-superclass-object" relationship to perform some powerful manipulations. For example, a drawing application can maintain a list of shapes to display. If all the shape types extend the same superclass directly or indirectly, the drawing program can store all the shapes in an array (or other data structure) of superclass objects. As we will see in this chapter, this ability to process a set of objects as a single type is a key thrust of object-oriented programming.

We add a new form of member access control in this chapter, namely **`protected`** access. Subclass methods and methods of other classes in the same package as the superclass can access **`protected`** superclass members.

Experience in building software systems indicates that significant portions of the code deal with closely related special cases. It becomes difficult in such systems to see the "big picture" because the designer and the programmer become preoccupied with the special cases. Object-oriented programming provides several ways of "seeing the forest through the trees."

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The programmer and designer concentrate on the big picture—the commonality among objects in the system—rather than the special cases. This process is called *abstraction*.

If a procedural program has many closely related special cases, then it is common to see **`switch`** structures or nested **`if/else`** structures that distinguish among the special cases and provide the processing logic to deal with each case individually. We will show how to use inheritance and polymorphism to replace such **`switch`** logic with much simpler logic.

We distinguish between the *"is a" relationship* and the *"has a" relationship*. "Is a" is inheritance. In an "is a" relationship, an object of a subclass type may also be treated as an object of its superclass type. "Has a" is composition (as we discussed in Chapter 8). In a "has a" relationship, a class object has one or more objects of other classes as members. For example, a car *has a* steering wheel.

A subclass's methods might need to access certain of its superclass's instance variables and methods. A crucial aspect of software engineering in Java is that a subclass cannot access the **`private`** members of its superclass. If a subclass could access the superclass's **`private`** members, this would violate information hiding in the superclass.

Software Engineering Observation 9.1

*A subclass cannot directly access **`private`** members of its superclass.*

Testing and Debugging Tip 9.1

*Hiding **`private`** members is a tremendous help in testing, debugging and correctly modifying systems. If a subclass could access its superclass's **`private`** members, it would be possible for classes derived from that subclass to access that data as well, and so on. This would propagate access to what is supposed to be **`private`** data, and the benefits of information hiding would be lost throughout the class hierarchy.*

However, a subclass can access the **`public`** and **`protected`** members of its superclass. A subclass also can use the package access members of its superclass if the subclass and superclass are in the same package. Superclass members that should not be accessible to a subclass via inheritance are declared **`private`** in the superclass. A subclass can effect state changes in superclass **`private`** members only through **`public`**, **`protected`** and package access methods provided in the superclass and inherited into the subclass. [*Note*: We use **`protected`** instance variables in this chapter to demonstrate how they work. Several of the exercises in this chapter require that you use only private instance variables, to maintain encapsulation.]

Software Engineering Observation 9.2

*To preserve encapsulation, all instance variables should be declared **`private`** and should be accessible only via* set *and* get *methods of the class.*

A problem with inheritance is that a subclass can inherit methods that it does not need or should not have. It is the class designer's responsibility to ensure that the capabilities provided by a class are appropriate for future subclasses. Even when the superclass methods are appropriate for the subclasses, it is common for a sublcass to require the method to perform a task in a manner that is specific to the subclass. In such cases, the superclass method can be *overridden* (redefined) in the subclass with an appropriate implementation.

Perhaps most exciting is the notion that new classes can inherit from abundant *class libraries*, such as those provided with the Java API. Organizations develop their own class

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libraries and can take advantage of other libraries available worldwide. Someday, most software might be constructed from *standardized reusable components*, just as hardware is often constructed today. This will help meet the challenges of developing the ever more powerful software we will need in the future.

9.2 Superclasses and Subclasses

Often an object of one class "is an" object of another class as well. A rectangle certainly *is a* quadrilateral (as are squares, parallelograms and trapezoids). Thus, class **`Rectangle`** can be said to *inherit* from class **`Quadrilateral`**. In this context, class **`Quadrilateral`** is a superclass, and class **`Rectangle`** is a subclass. A rectangle *is a* specific type of quadrilateral, but it is incorrect to claim that a quadrilateral *is a* rectangle (the quadrilateral could be a parallelogram). Figure 9.1 shows several simple inheritance examples of superclasses and potential subclasses.

Inheritance normally produces subclasses with *more* features than their superclasses, so the terms superclass and subclass can be confusing. There is another way, however, to view these terms that makes perfectly good sense. Because every subclass object "is an" object of its superclass, and because one superclass can have many subclasses, the set of objects represented by a superclass is normally larger than the set of objects represented by any of that superclass's subclasses. For example, the superclass **`Vehicle`** represents in a generic manner all vehicles, such as cars, trucks, boats, bicycles and so on. However, subclass **`Car`** represents only a small subset of all the **`Vehicle`**s in the world.

Inheritance relationships form tree-like hierarchical structures. A superclass exists in a hierarchical relationship with its subclasses. A class can certainly exist by itself, but it is when a class is used with the mechanism of inheritance that the class becomes either a superclass that supplies attributes and behaviors to other classes or a subclass that inherits those attributes and behaviors. Frequently, one class is both a subclass and a superclass.

Superclass	Subclasses
`Student`	`GraduateStudent` `UndergraduateStudent`

`Shape`	`Circle`
	`Triangle`
	`Rectangle`

`Loan`	`CarLoan`
	`HomeImprovementLoan`
	`MortgageLoan`

`Employee`	`FacultyMember` `StaffMember`
`Account`	`CheckingAccount` `SavingsAccount`

Fig. 9.1 Some simple inheritance examples in which the subclass "is a" superclass.

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Let us develop a simple inheritance hierarchy. A typical university community has thousands of people who are community members. These people consist of employees, students and alumni. Employees are either faculty members or staff members. Faculty members are either administrators (such as deans and department chairpersons) or teaching faculty. This yields the inheritance hierarchy shown in Fig. 9.2. Note that the inheritance hierarchy could contain many other classes. For example, students can be graduate students or undergraduate students. Undergraduate students can be freshman, sophomores, juniors, and seniors. And so on. The arrows in the hierarchy represent the "is a" relationship. For example, based on this class hierarchy that we can state, "an **Employee** *is a* **CommunityMember**," or "a **Teacher** *is a* **Faculty** member." **CommunityMember** is the *direct superclass* of **Employee**, **Student** and **Alumni**. **CommunityMember** is an *indirect superclass* of all the other classes in the hierarchy diagram. Note that class **Employee** is both a subclass of **CommunityMember** and a superclass of **Faculty** and **Staff**.

Also, starting from the bottom of the diagram, you can follow the arrows and apply the *is a* relationship all the way up to the topmost superclass in the hierarchy. For example, an **Administrator** *is a* **Faculty** member, *is an* **Employee** and *is a* **CommunityMember**. And, in Java, an **Administrator** also *is an* **Object** because all classes in Java have **Object** as one of their direct or indirect superclasses. Thus, all classes in Java are related in a hierarchical relationship in which they share the 11 methods defined by class **Object**, which include the **toString** and **finalize** methods discussed previously. Other methods of class **Object** are discussed as they are needed in the text.

Another substantial inheritance hierarchy is the **Shape** hierarchy of Figure 9.3. There are abundant examples of hierarchies in the real world, but students are not accustomed to categorizing the real world in this manner, so it takes some adjustment in their thinking. Actually, biology students have had some practice with hierarchies. Everything we study in biology is grouped into a hierarchy headed by living things and these can be plants or animals and so on.

To specify that class **TwoDimensionalShape** is derived from (or inherits from) class **Shape**, class **TwoDimensionalShape** could be defined in Java as follows:

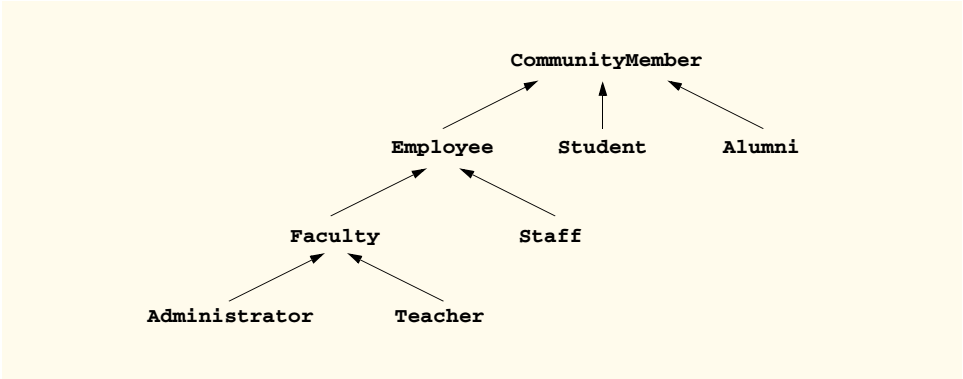

Fig. 9.2 An inheritance hierarchy for university **CommunityMember**s.

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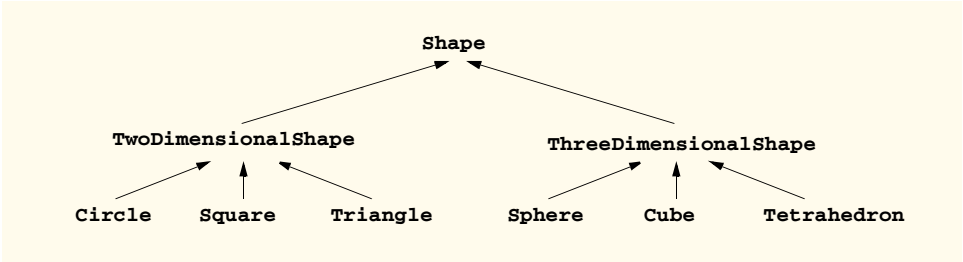

Fig. 9.3 A portion of a **Shape** class hierarchy.

```
public class TwoDimensionalShape extends Shape {
   ...
}
```

With inheritance, **private** members of a superclass are not directly accessible from that class's subclasses. Package access members of the superclass are accessible in a subclass only if both the superclass and its subclass are in the same package. All other superclass members become members of the subclass, using their original member access (i.e., **public** members of the superclass become **public** members of the subclass, and **protected** members of the superclass become **protected** members of the subclass).

Software Engineering Observation 9.3

Constructors are never inherited—they are specific to the class in which they are defined.

It is possible to treat superclass objects and subclass objects similarly; that commonality is expressed in the attributes and behaviors of the superclass. Objects of all classes derived from a common superclass can all be treated as objects of that superclass.

We will consider many examples in which we can take advantage of this inheritance relationship with an ease of programming not available in non-object-oriented languages such as C.

9.3 protected Members

A superclass's **public** members are accessible anywhere the program has a reference to that superclass type or one of its subclass types. A superclass's **private** members are accessible only in methods of that superclass.

A superclass's **protected** access members serve as an intermediate level of protection between **public** and **private** access. A superclass's **protected** members may be accessed only by methods of the superclass, by methods of subclasses and by methods of other classes in the same package (**protected** members have package access).

Subclass methods can normally refer to **public** and **protected** members of the superclass simply by using the member names. When a subclass method overrides a superclass method, the superclass method may be accessed from the subclass by preceding the superclass method name with keyword **super** followed by the dot operator (**.**). This technique is illustrated several times throughout the chapter.

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9.4 Relationship between Superclass Objects and Subclass Objects

An object of a subclass can be treated as an object of its superclass. This makes possible some interesting manipulations. For example, despite the fact that objects of a variety of classes derived from a particular superclass might be quite different from one another, we can create an array of references to them—as long as we treat them as superclass objects. But the reverse is not true: A superclass object cannot always be treated a subclass object. For example, a **Shape** is not always a **Circle**.

However, an explicit cast can be used to convert a superclass reference to a subclass reference. This can be done only when the superclass reference is referencing a subclass object; otherwise, Java will indicate a ***ClassCastException***—an indication that the cast operation is not allowed. Exceptions are discussed in detail in Chapter 14.

Common Programming Error 9.1

Assigning an object of a superclass to a subclass reference (without a cast) is a syntax error.

Software Engineering Observation 9.4

If an object has been assigned to a reference of one of its superclasses, it is acceptable to cast that object back to its own type. In fact, this must be done in order to send that object any of its messages that do not appear in that superclass.

Our first example consists of two classes. Figure 9.4 shows a **Point** class definition. Figure 9.5 shows a **Circle** class definition. We will see that class **Circle** inherits from class **Point**. Figure 9.6 shows application class **InheritanceTest**, which demonstrates assigning subclass references to superclass references and casting superclass references to subclass references.

Every applet defined previously has used some of the techniques presented here. We now formalize the inheritance concept. In Chapter 3, we stated that every class definition in Java must extend another class. However, notice in Fig. 9.4 that class **Point** (line 4) does not use the **extends** keyword explicitly. If a new class definition does not extend an existing class definition explicitly, Java implicitly uses class **Object** (package **java.lang**) as the superclass for the new class definition. Class **Object** provides a set of methods that can be used with any object of any class.

Software Engineering Observation 9.5

*Every class in Java implicitly extends **Object**, unless it is specified otherwise in the first line of the class definition, in which case the class indirectly extends **Object**. Thus, class **Object** is the superclass of the entire Java class hierarchy.*

Let us first examine the **Point** class definition (Fig. 9.4). The **public** services of class **Point** include methods **setPoint**, **getX**, **getY**, **toString** and two **Point** constructors. The instance variables **x** and **y** of **Point** are specified as **protected**. This prevents clients of **Point** objects from accessing the data directly (unless they are classes in the same package), but enables classes derived from **Point** to access the inherited instance variables directly. If the data were specified as **private**, the non**private** methods of **Point** would have to be used to access the data, even by subclasses. Note that class **Point**'s **toString** method overrides the original **toString** method inherited from class **Object**.

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```
1  // Fig. 9.4: Point.java
2  // Definition of class Point
3
4  public class Point {
5     protected int x, y; // coordinates of Point
6
7     // No-argument constructor
8     public Point()
9     {
10       // implicit call to superclass constructor occurs here
11       setPoint( 0, 0 );
12    }
13
14    // constructor
15    public Point( int xCoordinate, int yCoordinate )
16    {
17       // implicit call to superclass constructor occurs here
18       setPoint( xCoordinate, yCoordinate );
19    }
20
21    // set x and y coordinates of Point
22    public void setPoint( int xCoordinate, int yCoordinate )
23    {
24       x = xCoordinate;
25       y = yCoordinate;
26    }
27
28    // get x coordinate
29    public int getX()
30    {
31       return x;
32    }
33
34    // get y coordinate
35    public int getY()
36    {
37       return y;
38    }
39
40    // convert into a String representation
41    public String toString()
42    {
43       return "[" + x + ", " + y + "]";
44    }
45
46 }  // end class Point
```

Fig. 9.4 **Point** class definition.

Class **Point**'s constructors (lines 8–12 and 15–19) must call class **Object**'s constructor. In fact, every subclass constructor is required to call its direct superclass's constructor as its first task, either implicitly or explicitly (the syntax for this call is discussed with class **Circle** momentarily). If there is no explicit call to the superclass constructor,

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Java automatically attempts to call the superclass's default constructor. Note that lines 10 and 17 are comments indicating where the call to the superclass **Object**'s default constructor occurs.

Software Engineering Observation 9.6

Every subclass constructor must call one of the direct superclass constructors explicitly or implicitly. Implicit calls can be made only to the no-argument constructor of the superclass. If the superclass does not provide a no-argument constructor, all direct subclasses of that class must call one of superclass's constructors explicitly.

Class **Circle** (Fig. 9.5) inherits from class **Point** as specified with the **extends** keyword on line 4. Keyword **extends** in the class definition indicates inheritance. All the (non**private**) members of class **Point** (except the constructors) are inherited into class **Circle**. Thus, the **public** interface to **Circle** includes the **Point** class's **public** methods as well as the two overloaded **Circle** constructors and **Circle** methods **setRadius**, **getRadius**, **area** and **toString**. Notice that method **area** (lines 38–41) uses predefined constant ***Math.PI*** from class **Math** (package **java.lang**) to calculate the area of a circle.

```
1  // Fig. 9.5: Circle.java
2  // Definition of class Circle
3
4  public class Circle extends Point {  // inherits from Point
5     protected double radius;
6
7     // no-argument constructor
8     public Circle()
9     {
10       // implicit call to superclass constructor occurs here
11       setRadius( 0 );
12    }
13
14    // constructor
15    public Circle( double circleRadius, int xCoordinate,
16       int yCoordinate )
17    {
18       // call superclass constructor to set coordinates
19       super( xCoordinate, yCoordinate );
20
21       // set radius
22       setRadius( circleRadius );
23    }
24
25    // set radius of Circle
26    public void setRadius( double circleRadius )
27    {
28       radius = ( circleRadius >= 0.0 ? circleRadius : 0.0 );
29    }
30
```

Fig. 9.5 **Circle** class definition (part 1 of 2).

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```
31      // get radius of Circle
32      public double getRadius()
33      {
34         return radius;
35      }
36
37      // calculate area of Circle
38      public double area()
39      {
40         return Math.PI * radius * radius;
41      }
42
43      // convert the Circle to a String
44      public String toString()
45      {
46         return "Center = " + "[" + x + ", " + y + "]" +
47                "; Radius = " + radius;
48      }
49
50   }  // end class Circle
```

Fig. 9.5 **`Circle`** class definition (part 2 of 2).

The **`Circle`** constructors (lines 8–12 and 15–23) must invoke a **`Point`** constructor to initialize the superclass portion of a **`Circle`** object (i.e., variables **`x`** and **`y`** inherited from **`Point`**). The default constructor at lines 8–12 does not call a **`Point`** constructor explicitly, so Java automatically calls class **`Point`**'s default constructor (defined at line 8 of Fig. 9.4) that initializes superclass members **`x`** and **`y`** to zeros. If class **`Point`** contained only the constructor with arguments (i.e., did not provide a default constructor), a compiler error would occur.

Line 19 in the body of the second **`Circle`** constructor explicitly invokes the **`Point`** constructor (defined at line 15 of Fig. 9.4) by using the *superclass constructor call syntax*—keyword ***`super`*** followed by a set of parentheses containing the arguments to the superclass constructor. In this case, the arguments are the values **`xCoordinate`** and **`yCoordinate`** that are used by the **`Point`** constructor to initialize the superclass members **`x`** and **`y`**). The call to the superclass constructor must be the first line in the body of the subclass constructor. To call the superclass default constructor explicitly, use the statement

```
super();  // explicit call to superclass default constructor
```

Common Programming Error 9.2

*It is a syntax error if a **`super`** call by a subclass to its superclass constructor is not the first statement in the subclass constructor.*

Common Programming Error 9.3

*It is a syntax error if the arguments to a **`super`** call by a subclass to its superclass constructor do not match the parameters specified in one of the superclass constructor definitions.*

A subclass can redefine a superclass method by using the same signature; this is called *overriding* a superclass method. When that method is mentioned by name in the subclass,

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the subclass version is automatically called. We have actually been overriding methods in every applet in the book. When we extend **JApplet** to create a new applet class, the new class inherits versions of **init** and **paint** (and many other methods). Each time we defined **init** or **paint**, we were overriding the original version that was inherited. Also, when we provided method **toString** for many of the classes in Chapter 8, we were overriding the original version of **toString** provided by class **Object**. As we will see in Fig. 9.8, the **super** reference followed by the dot operator can be used to access the original superclass version of that method from the subclass.

Note that class **Circle**'s **toString** method (lines 44–48) overrides the **Point** class **toString** method (lines 41–44 of Fig. 9.4). Class **Point**'s **toString** method overrides the original **toString** method provided by class **Object**. Actually, every class inherits a **toString** method, because class **Object** provides the original **toString** method. This method converts an object of any class into a **String** representation and is sometimes called implicitly by the program (e.g., when an object is concatenated with a **String**). **Circle** method **toString** directly accesses the **protected** instance variables **x** and **y** that were inherited from class **Point**. Method **toString** uses the values of **x** and **y** as part of the **Circle**'s **String** representation. Actually, if you study class **Point**'s **toString** method and class **Circle**'s **toString** method, you will notice that **Circle**'s **toString** uses the same formatting as **Point**'s **toString** for the **Point** parts of the **Circle**. Also, recall *Software Engineering Observation 8.14,* indicating that, if a method exists that performs part of another method's task, call the method. **Point**'s **toString** performs part of the task of **Circle**'s **toString**. To call **Point**'s **toString** from class **Circle**, use the expression

```
super.toString()
```

Software Engineering Observation 9.7

A redefinition of a superclass method in a subclass need not have the same signature as the superclass method. Such a redefinition is not method overriding; rather, it is an example of method overloading.

Software Engineering Observation 9.8

*Any object can be converted to a **String** with an explicit or implicit call to the object's **toString** method.*

Software Engineering Observation 9.9

*Each class should override method **toString** to return useful information about objects of that class.*

Common Programming Error 9.4

It is a syntax error if a method in a superclass and a method in its subclass have the same signature but a different return type.

The **InheritanceTest** application (Fig. 9.6) instantiates **Point** object **point1** and **Circle** object **circle1** at lines 18–19 in **main**. The **String** representations of each object are assigned to **String output** to show that they were initialized correctly (lines 21–22). See the first two lines in the output screen capture to confirm this.

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```
1  // Fig. 9.6: InheritanceTest.java
2  // Demonstrating the "is a" relationship
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 public class InheritanceTest {
11
12    // test classes Point and Circle
13    public static void main( String args[] )
14    {
15       Point point1, point2;
16       Circle circle1, circle2;
17
18       point1 = new Point( 30, 50 );
19       circle1 = new Circle( 2.7, 120, 89 );
20
21       String output = "Point point1: " + point1.toString() +
22          "\nCircle circle1: " + circle1.toString();
23
24       // use "is a" relationship to refer to a Circle
25       // with a Point reference
26       point2 = circle1;   // assigns Circle to a Point reference
27
28       output += "\n\nCircle circle1 (via point2 reference): " +
29          point2.toString();
30
31       // use downcasting (casting a superclass reference to a
32       // subclass data type) to assign point2 to circle2
33       circle2 = ( Circle ) point2;
34
35       output += "\n\nCircle circle1 (via circle2): " +
36          circle2.toString();
37
38       DecimalFormat precision2 = new DecimalFormat( "0.00" );
39       output += "\nArea of c (via circle2): " +
40          precision2.format( circle2.area() );
41
42       // attempt to refer to Point object with Circle reference
43       if ( point1 instanceof Circle ) {
44          circle2 = ( Circle ) point1;
45          output += "\n\ncast successful";
46       }
47       else
48          output += "\n\npoint1 does not refer to a Circle";
49
50       JOptionPane.showMessageDialog( null, output,
51          "Demonstrating the \"is a\" relationship",
52          JOptionPane.INFORMATION_MESSAGE );
53
```

Fig. 9.6 Assigning subclass references to superclass references (part 1 of 2).

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```
54          System.exit( 0 );
55       }
56
57    }  // end class InheritanceTest
```

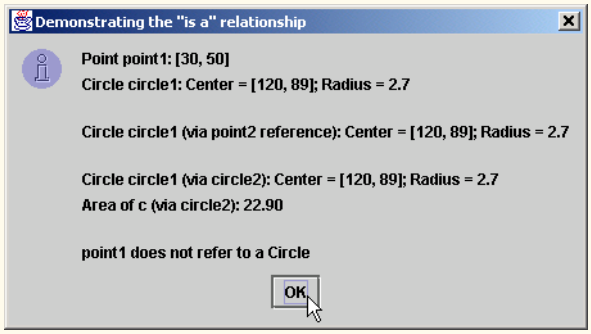

Fig. 9.6 Assigning subclass references to superclass references (part 2 of 2).

Line 26 assigns **`circle1`** (a reference to a subclass **`Circle`** object) to **`point2`** (a superclass **`Point`** reference). It is always acceptable in Java to assign a subclass reference to a superclass reference, because of the "is a" relationship of inheritance. A **`Circle`** *is a* **`Point`** because class **`Circle`** extends class **`Point`**. Assigning a superclass reference to a subclass reference is dangerous, as we will see.

Lines 28–29 append the result of **`point2.toString()`** to **`output`**. Interestingly, when **`point2`** is sent the **`toString`** message, Java knows that the object really is a **`Circle`**, so it chooses the **`Circle`** class's **`toString`** rather than the **`Point`** class's **`toString`** as you might have expected. This is an example of *polymorphism* and *dynamic binding*—concepts we treat in depth later in this chapter. The compiler looks at the preceding expression and asks the question, "Does the data type of the reference **`point2`** (i.e., **`Point`**) have a **`toString`** method with no arguments?" The answer to this question is yes (per **`Point`**'s **`toString`** definition on line 41 of Fig. 9.4). The compiler simply checks the syntax of the expression and ensures that the method exists. At execution time, the interpreter asks the question, "What type is the object to which **`point2`** refers?" Every object in Java knows its own data type, so the answer to the question is **`point2`** refers to a **`Circle`** object. Based on this answer, the interpreter calls the **`toString`** method of the actual object's data type—class **`Circle`**'s **`toString`** method. See the third line of the screen capture to confirm this. The two key programming techniques we used to achieve this polymorphism effect are

1. extending class **`Point`** to create class **`Circle`**, and
2. overriding method **`toString`** with the exact same signature in class **`Point`** and class **`Circle`**.

Line 33 casts **`point2`**, which admittedly is referencing a **`Circle`** at this time in the program's execution, to a **`Circle`** and assigns the result to **`circle2`** (this cast would be dangerous if **`point2`** were really referencing a **`Point`**, as we will soon discuss). Then we use **`circle2`** to append to **`output`** the various facts about **`circle2`**. Lines 35–36

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invoke method **toString** to append the **String** representation of the **Circle**. Lines 39–40 append the **area** of the **Circle** to **output**.

Next, the **if/else** structure at lines 43–48 attempts a dangerous cast in line 44. We cast **point1**, which refers to a Point object, to a **Circle**. If the program attempts to execute this statement, Java would determine that **point1** really refers to a **Point**, recognize the cast to **Circle** as being dangerous and indicate an improper cast with **ClassCastException** message. However, we prevent this statement from executing with the **if** condition

```
if ( point1 instanceof Circle ) {
```

that uses operator ***instanceof*** to determine whether the object to which **point1** refers *is a* **Circle**. This condition evaluates to **true** only if the object to which **point1** refers *is a* **Circle**; otherwise, the condition evaluates to **false**. Reference **point1** does not refer to a **Circle**, so the condition fails, and a **String** indicating that **point1** does not refer to a **Circle** is appended to **output**.

If we remove the **if** test from the program and execute the program, the following message is generated at execution time:

```
Exception in thread "main" java.lang.ClassCastException: Point
        at InheritanceTest.main(InheritanceTest.java:43)
```

Such error messages normally include the file name (**InheritanceTest.java**) and line number at which the error occurred (**43**) so you can go to that specific line in the program for debugging.

9.5 Constructors and Finalizers in Subclasses

When an object of a subclass is instantiated, the superclass's constructor should be called to do any necessary initialization of the superclass instance variables of the subclass object. An explicit call to the superclass constructor (via the **super** reference) can be provided as the first statement in the subclass constructor. Otherwise, the subclass constructor will call the superclass default constructor (or no-argument constructor) implicitly.

Superclass constructors are not inherited by subclasses. Subclass constructors, however, can call superclass constructors via the **super** reference.

Software Engineering Observation 9.10

When an object of a subclass is created, first the subclass constructor calls the superclass constructor (explicitly via ***super*** *or implicitly), the superclass constructor executes, then the remainder of the subclass constructor's body executes.*

If the classes in your class hierarchy define **finalize** methods, the subclass **finalize** method as its last action should invoke the superclass **finalize** method to ensure that all parts of an object are finalized properly if the garbage collector reclaims the memory for the object.

The application of Fig. 9.7–Fig. 9.9 shows the order in which superclass and subclass constructors and finalizers are called. For the purpose of this example, class **Point** and class **Circle** are simplified.

Class **Point** (Fig. 9.7) contains two constructors, a finalizer, a **toString** method and **protected** instance variables **x** and **y**. The constructor and finalizer each print that they are executing, then display the **Point** for which they are invoked. Note the use of

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this in the **System.out.println** calls to cause an implicit call to method **toString**. Notice the first line of the **finalize** method (line 23). Method **finalize** should always be defined as **protected** so subclasses have access to the method but classes that simply use **Point** objects do not.

Class **Circle** (Fig. 9.8) derives from **Point** and contains two constructors, a finalizer, a **toString** method and protected instance variable **radius**. The constructor and finalizer each print that they are executing, then display the **Circle** for which they are invoked. Note that the **Circle** method **toString** invokes **Point**'s **toString** via **super** (line 19).

Software Engineering Observation 9.11

When a superclass method is overridden in a subclass, it is common to have the subclass version call the superclass version and do some additional work. In this scenario, the superclass method performs the tasks common to all subclasses of that class, and the subclass method performs additional tasks specific to a given subclass.

```
1  // Fig. 9.7: Point.java
2  // Definition of class Point
3  public class Point extends Object {
4     protected int x, y; // coordinates of the Point
5
6     // no-argument constructor
7     public Point()
8     {
9        x = 0;
10       y = 0;
11       System.out.println( "Point constructor: " + this );
12    }
13
14    // constructor
15    public Point( int xCoordinate, int yCoordinate )
16    {
17       x = xCoordinate;
18       y = yCoordinate;
19       System.out.println( "Point constructor: " + this );
20    }
21
22    // finalizer
23    protected void finalize()
24    {
25       System.out.println( "Point finalizer: " + this );
26    }
27
28    // convert Point into a String representation
29    public String toString()
30    {
31       return "[" + x + ", " + y + "]";
32    }
33
34 }  // end class Point
```

Fig. 9.7 **Point** class definition to demonstrate when constructors and finalizers are called.

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```
1  // Fig. 9.8: Circle.java
2  // Definition of class Circle
3  public class Circle extends Point {  // inherits from Point
4     protected double radius;
5
6     // no-argument constructor
7     public Circle()
8     {
9        // implicit call to superclass constructor here
10       radius = 0;
11       System.out.println( "Circle constructor: " + this );
12    }
13
14    // Constructor
15    public Circle( double circleRadius, int xCoordinate,
16       int yCoordinate )
17    {
18       // call superclass constructor
19       super( xCoordinate, yCoordinate );
20
21       radius = circleRadius;
22       System.out.println( "Circle constructor: " + this );
23    }
24
25    // finalizer
26    protected void finalize()
27    {
28       System.out.println( "Circle finalizer: " + this );
29       super.finalize();  // call superclass finalize method
30    }
31
32    // convert the Circle to a String
33    public String toString()
34    {
35       return "Center = " + super.toString() +
36              "; Radius = " + radius;
37    }
38
39 }  // end class Circle
```

Fig. 9.8 **`Circle`** class definition to demonstrate when constructors and finalizers are called.

Common Programming Error 9.5

*When an overridden method calls the superclass version of the same method, not using keyword **`super`** to reference the superclass's method causes infinite recursion, because the subclass method actually calls itself.*

Common Programming Error 9.6

*Cascading **`super`** reference to refer to a member (method or variable) several levels up the hierarchy (as in **`super.super.x`**) is a syntax error.*

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Application class **Test** (Fig. 9.9) uses this **Point/Circle** inheritance hierarchy. The application begins in method **main** by instantiating **Circle** object **circle1** (line 11). This invokes the **Circle** constructor at line 15 of Fig. 9.8, which immediately invokes the **Point** constructor at line 15 of Fig. 9.7. The **Point** constructor outputs the values received from the **Circle** constructor by implicitly calling method **toString** and returns program control to the **Circle** constructor. Then the **Circle** constructor outputs the complete **Circle** by calling method **toString**. Notice that the first two lines of the output from this program both show values for **x**, **y** and **radius**. Polymorphism is once again causing the **Circle**'s **toString** method to execute because it is a **Circle** object that is being created. When **toString** is invoked from the **Point** constructor, **0.0** is displayed for the **radius** because the **radius** has not yet been initialized in the **Circle** constructor.

Circle object **circle2** is instantiated next. Again, the **Point** and **Circle** constructors both execute. Notice, in the command-line output window, that the body of the **Point** constructor is performed before the body of the **Circle** constructor, showing that objects are constructed "inside out."

```
1  // Fig. 9.9: Test.java
2  // Demonstrate when superclass and subclass
3  // constructors and finalizers are called.
4  public class Test {
5
6     // test when constructors and finalizers are called
7     public static void main( String args[] )
8     {
9        Circle circle1, circle2;
10
11       circle1 = new Circle( 4.5, 72, 29 );
12       circle2 = new Circle( 10, 5, 5 );
13
14       circle1 = null;  // mark for garbage collection
15       circle2 = null;  // mark for garbage collection
16
17       System.gc();     // call the garbage collector
18    }
19
20 }  // end class Test
```

```
Point constructor: Center = [72, 29]; Radius = 0.0
Circle constructor: Center = [72, 29]; Radius = 4.5
Point constructor: Center = [5, 5]; Radius = 0.0
Circle constructor: Center = [5, 5]; Radius = 10.0
Circle finalizer: Center = [72, 29]; Radius = 4.5
Point finalizer: Center = [72, 29]; Radius = 4.5
Circle finalizer: Center = [5, 5]; Radius = 10.0
Point finalizer: Center = [5, 5]; Radius = 10.0
```

Fig. 9.9 Order in which constructors and finalizers are called.

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Lines 14–15 set **circle1** to **null**, then set **circle2** to **null**. Each of these objects is no longer needed in the program, so Java marks the memory occupied by **circle1** and **circle2** for *garbage collection.* Java guarantees that, before the garbage collector runs to reclaim the space for each of these objects, the **finalize** methods for each object will be called. The garbage collector is a low-priority thread that runs automatically whenever processor time is available. We choose here to ask the garbage collector to run with a call to class **System**'s **static** method **gc** in line 17. Java does not guarantee the order in which objects will be garbage collected; therefore, it cannot guarantee which object's finalizer will execute first. Notice, in the command-line output window, that **finalize** methods are called for both the **Circle** and **Point** when each **Circle** object is garbage collected.

9.6 Implicit Subclass-Object-to-Superclass-Object Conversion

Despite the fact that a subclass object also "is a" superclass object, the subclass type and the superclass type are different. Subclass objects can be treated as superclass objects. This makes sense because the subclass has members corresponding to each of the superclass members—remember that the subclass normally has more members than the superclass has. Assignment in the other direction is not allowed because assigning a superclass object to a subclass reference would leave the additional subclass members undefined.

A reference to a subclass object could be implicitly converted into a reference to a superclass object because a subclass object *is a* superclass object through inheritance.

There are four possible ways to mix and match superclass references and subclass references with superclass objects and subclass objects:

1. Referring to a superclass object with a superclass reference is straightforward.
2. Referring to a subclass object with a subclass reference is straightforward.
3. Referring to a subclass object with a superclass reference is safe, because the subclass object *is an* object of its superclass as well. Such code can refer only to superclass members. If this code refers to subclass-only members through the superclass reference, the compiler will report a syntax error.
4. Referring to a superclass object with a subclass reference is a syntax error.

As convenient as it might be to treat subclass objects as superclass objects, and to do this by manipulating all these objects with superclass references, there appears to be a problem. In a payroll system, for example, we would like to be able to walk through an array of employees and calculate the weekly pay for each person. But intuition suggests that using superclass references would enable the program to call only the superclass payroll calculation routine (if indeed there is such a routine in the superclass). We need a way to invoke the proper payroll calculation routine for each object, whether it is a superclass object or a subclass object, and to do this simply by using the superclass reference. Actually, this is precisely how Java behaves and is discussed in this chapter when we consider polymorphism and dynamic binding.

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9.7 Software Engineering with Inheritance

We can use inheritance to customize existing software. When we use inheritance to create a new class from an existing class, the new class inherits the attributes and behaviors of an existing class; then we can add attributes and behaviors or override superclass behaviors to customize the class to meet our needs.

It can be difficult for students to appreciate the problems faced by designers and implementers on large-scale software projects in industry. People experienced on such projects will invariably state that a key to improving the software development process is encouraging software reuse. Object-oriented programming in general, and Java in particular, certainly does this.

It is the availability of substantial and useful class libraries that delivers the maximum benefits of software reuse through inheritance. As interest in Java grows, interest in Java class libraries will increase. Just as shrink-wrapped software produced by independent software vendors became an explosive growth industry with the arrival of the personal computer, so, too, will the creation and sale of Java class libraries. Application designers will build their applications with these libraries, and library designers will be rewarded by having their libraries wrapped with the applications. What we see coming is a massive worldwide commitment to the development of Java class libraries for a huge variety of applications arenas.

Software Engineering Observation 9.12

Creating a subclass does not affect its superclass's source code or the superclass's Java bytecodes; the integrity of a superclass is preserved by inheritance.

A superclass specifies commonality. All classes derived from a superclass inherit the capabilities of that superclass. In the object-oriented design process, the designer looks for commonality among a set of classes and factors it out to form desirable superclasses. Subclasses are then customized beyond the capabilities inherited from the superclass.

Software Engineering Observation 9.13

Just as the designer of non-object-oriented systems should avoid unnecessary proliferation of functions, the designer of object-oriented systems should avoid unnecessary proliferation of classes. Proliferating classes creates management problems and can hinder software reusability, simply because it is more difficult for a potential user of a class to locate that class in a huge collection. The trade-off is to create fewer classes, each providing substantial additional functionality, but such classes might be too rich for certain users.

Performance Tip 9.1

When creating a new class, inherit from the class "closest" to what you need—i.e., the one that provides the minimum set of capabilities required for a new class to perform its tasks. Subclasses could inherit data and functionality that they will not use, in which case memory and processing resources may be wasted.

Note that reading a set of subclass declarations can be confusing because inherited members are not shown, but inherited members are nevertheless present in the subclasses. A similar problem can exist in the documentation of subclasses.

Software Engineering Observation 9.14

In an object-oriented system, classes are often closely related. "Factor out" common attributes and behaviors and place these in a superclass. Then use inheritance to form subclasses without having to repeat common attributes and behaviors.

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Software Engineering Observation 9.15

Modifications to a superclass do not require subclasses to change as long as the public interface to the superclass remains unchanged.

9.8 Composition vs. Inheritance

We have discussed *is a* relationships that are implemented by inheritance. We have also discussed *has a* relationships (and seen examples in preceding chapters) in which a class has objects of other classes as members—such relationships create new classes by *composition* of existing classes. For example, given the classes **Employee**, **BirthDate** and **TelephoneNumber**, it is improper to say that an **Employee** *is a* **BirthDate** or that an **Employee** *is a* **TelephoneNumber**. But it is certainly appropriate to say that an **Employee** *has a* **BirthDate** and that an **Employee** *has a* **TelephoneNumber**.

9.9 Case Study: Point, Circle, Cylinder

Now let us consider a substantial inheritance example. We consider a point, circle, cylinder hierarchy. First we develop and use class **Point** (Fig. 9.10 and Fig. 9.11). Then we present an example in which we derive class **Circle** from class **Point** (Fig. 9.12 and Fig. 9.13). Finally, we present an example in which we derive class **Cylinder** from class **Circle** (Fig. 9.14 and Fig. 9.15).

Figure 9.10 is the class **Point** definition. Class **Point** is defined as part of package **com.deitel.jhtp4.ch09** (line 3). Note that **Point**'s instance variables are **protected**. Thus, when class **Circle** is derived from class **Point**, the methods of class **Circle** will be able to reference coordinates **x** and **y** directly rather than using access methods. This could result in better performance.

```
1  // Fig. 9.10: Point.java
2  // Definition of class Point
3  package com.deitel.jhtp4.ch09;
4
5  public class Point {
6     protected int x, y; // coordinates of Point
7
8     // No-argument constructor
9     public Point()
10    {
11       // implicit call to superclass constructor occurs here
12       setPoint( 0, 0 );
13    }
14
15    // constructor
16    public Point( int xCoordinate, int yCoordinate )
17    {
18       // implicit call to superclass constructor occurs here
19       setPoint( xCoordinate, yCoordinate );
20    }
21
```

Fig. 9.10 **Point** class definition (part 1 of 2).

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```
22     // set x and y coordinates of Point
23     public void setPoint( int xCoordinate, int yCoordinate )
24     {
25        x = xCoordinate;
26        y = yCoordinate;
27     }
28
29     // get x coordinate
30     public int getX()
31     {
32        return x;
33     }
34
35     // get y coordinate
36     public int getY()
37     {
38        return y;
39     }
40
41     // convert into a String representation
42     public String toString()
43     {
44        return "[" + x + ", " + y + "]";
45     }
46
47  }  // end class Point
```

Fig. 9.10 **Point** class definition (part 2 of 2).

Figure 9.11 shows a **Test** application for testing class **Point**. The **main** method must use **getX** and **getY** to read the values of **protected** instance variables **x** and **y**. Remember that **protected** instance variables are accessible only to methods of their class, their subclasses and other classes in the same package. Also, note the implicit call to **toString** when **point** is added to a **String** at line 25.

```
1  // Fig. 9.11: Test.java
2  // Applet to test class Point
3
4  // Java extension packages
5  import javax.swing.JOptionPane;
6
7  // Deitel packages
8  import com.deitel.jhtp4.ch09.Point;
9
10 public class Test {
11
12    // test class Point
13    public static void main( String args[] )
14    {
15       Point point = new Point( 72, 115 );
16
```

Fig. 9.11 Testing class **Point** (part 1 of 2).

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```
17         // get coordinates
18         String output = "X coordinate is " + point.getX() +
19                         "\nY coordinate is " + point.getY();
20
21         // set coordinates
22         point.setPoint( 10, 10 );
23
24         // use implicit call to point.toString()
25         output += "\n\nThe new location of point is " + point;
26
27         JOptionPane.showMessageDialog( null, output,
28            "Demonstrating Class Point",
29            JOptionPane.INFORMATION_MESSAGE );
30
31         System.exit( 0 );
32      }
33
34   }  // end class Test
```

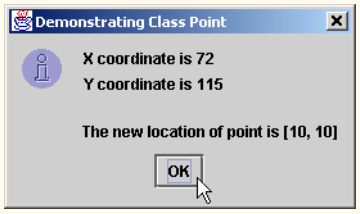

Fig. 9.11 Testing class **Point** (part 2 of 2).

Our next example imports the **Point** class definition from Fig. 9.10, so we do not show the class definition again here. Figure 9.12 shows the **Circle** class definition with the **Circle** method definitions. Note that class **Circle** **extends** class **Point**. This means that the **public** interface to **Circle** includes the **Point** methods as well as the **Circle** methods **setRadius**, **getRadius**, **area**, **toString** and the **Circle** constructors.

```
1  // Fig. 9.12: Circle.java
2  // Definition of class Circle
3  package com.deitel.jhtp4.ch09;
4
5  public class Circle extends Point {  // inherits from Point
6     protected double radius;
7
8     // no-argument constructor
9     public Circle()
10    {
11       // implicit call to superclass constructor occurs here
12       setRadius( 0 );
13    }
14
```

Fig. 9.12 **Circle** class definition (part 1 of 2).

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```
15      // constructor
16      public Circle( double circleRadius, int xCoordinate,
17         int yCoordinate )
18      {
19         // call superclass constructor to set coordinates
20         super( xCoordinate, yCoordinate );
21
22         // set radius
23         setRadius( circleRadius );
24      }
25
26      // set radius of Circle
27      public void setRadius( double circleRadius )
28      {
29         radius = ( circleRadius >= 0.0 ? circleRadius : 0.0 );
30      }
31
32      // get radius of Circle
33      public double getRadius()
34      {
35         return radius;
36      }
37
38      // calculate area of Circle
39      public double area()
40      {
41         return Math.PI * radius * radius;
42      }
43
44      // convert the Circle to a String
45      public String toString()
46      {
47         return "Center = " + "[" + x + ", " + y + "]" +
48                "; Radius = " + radius;
49      }
50
51   }  // end class Circle
```

Fig. 9.12 **Circle** class definition (part 2 of 2).

Application **Test** (Fig. 9.13) instantiates an object of class **Circle** (line 19), then uses *get* methods to obtain the information about the **Circle** object. Method **main** indirectly references the **protected** data of class **Circle** through method calls. Method **main** then uses *set* methods **setRadius** and **setPoint** to reset the radius and coordinates of the center of the circle. Finally, **main** displays the **Circle** object **circle** and calculates and displays its area.

```
1  // Fig. 9.13: Test.java
2  // Applet to test class Circle
3
```

Fig. 9.13 Testing class **Circle** (part 1 of 2).

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```
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 // Deitel packages
11 import com.deitel.jhtp4.ch09.Circle;
12
13 public class Test {
14
15    // test class Circle
16    public static void main( String args[] )
17    {
18       // create a Circle
19       Circle circle = new Circle( 2.5, 37, 43 );
20       DecimalFormat precision2 = new DecimalFormat( "0.00" );
21
22       // get coordinates and radius
23       String output = "X coordinate is " + circle.getX() +
24                "\nY coordinate is " + circle.getY() +
25                "\nRadius is " + circle.getRadius();
26
27       // set coordinates and radius
28       circle.setRadius( 4.25 );
29       circle.setPoint( 2, 2 );
30
31       // get String representation of Circle and calculate area
32       output +=
33          "\n\nThe new location and radius of c are\n" + circle +
34          "\nArea is " + precision2.format( circle.area() );
35
36       JOptionPane.showMessageDialog( null, output,
37          "Demonstrating Class Circle",
38          JOptionPane.INFORMATION_MESSAGE );
39
40       System.exit( 0 );
41    }
42
43 }  // end class Test
```

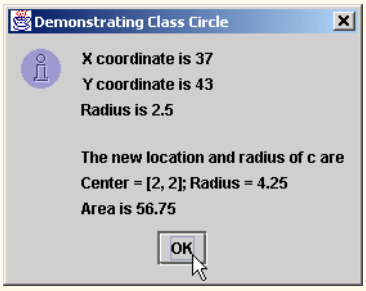

Fig. 9.13 Testing class **Circle** (part 2 of 2).

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Our last example is shown in Fig. 9.14 and Fig. 9.15. Figure 9.14 shows the **Cylinder** class definition with the **Cylinder** method definitions. Note that class **Cylinder** **extends** class **Circle**. This means that the **public** interface to **Cylinder** includes the **Circle** methods and **Point** methods as well as the **Cylinder** constructor and **Cylinder** methods **setHeight**, **getHeight**, **area** (which overrides the **Circle** **area** method), **volume** and **toString**.

```
1  // Fig. 9.14: Cylinder.java
2  // Definition of class Cylinder
3  package com.deitel.jhtp4.ch09;
4
5  public class Cylinder extends Circle {
6     protected double height;  // height of Cylinder
7
8     // no-argument constructor
9     public Cylinder()
10    {
11       // implicit call to superclass constructor here
12       setHeight( 0 );
13    }
14
15    // constructor
16    public Cylinder( double cylinderHeight, double cylinderRadius,
17       int xCoordinate, int yCoordinate )
18    {
19       // call superclass constructor to set coordinates/radius
20       super( cylinderRadius, xCoordinate, yCoordinate );
21
22       // set cylinder height
23       setHeight( cylinderHeight );
24    }
25
26    // set height of Cylinder
27    public void setHeight( double cylinderHeight )
28    {
29       height = ( cylinderHeight >= 0 ? cylinderHeight : 0 );
30    }
31
32    // get height of Cylinder
33    public double getHeight()
34    {
35       return height;
36    }
37
38    // calculate area of Cylinder (i.e., surface area)
39    public double area()
40    {
41       return 2 * super.area() +
42              2 * Math.PI * radius * height;
43    }
44
```

Fig. 9.14 Class **Cylinder** definition (part 1 of 2).

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```
45     // calculate volume of Cylinder
46     public double volume()
47     {
48        return super.area() * height;
49     }
50
51     // convert the Cylinder to a String
52     public String toString()
53     {
54        return super.toString() + "; Height = " + height;
55     }
56
57  }  // end class Cylinder
```

Fig. 9.14 Class **Cylinder** definition (part 2 of 2).

Method **main** of the **Test** application (Fig. 9.15) instantiates an object of class **Cylinder** (line 19), then uses *get* methods (lines 23–26) to obtain information about the **Cylinder** object. Again, the **Test** applications's **main** method cannot reference directly the **protected** data of class **Cylinder**. Method **main** uses *set* methods **setHeight**, **setRadius** and **setPoint** (lines 29–31) to reset the **height**, **radius** and coordinates of the **Cylinder**. Then **main** uses **toString**, **area** and **volume** to print the attributes and some facts about the **Cylinder**. Figure 9.15 is a **Test** application to test class **Cylinder**'s capabilities.

```
1  // Fig. 9.15: Test.java
2  // Application to test class Cylinder
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 // Deitel packages
11 import com.deitel.jhtp4.ch09.Cylinder;
12
13 public class Test {
14
15    // test class Cylinder
16    public static void main( String args[] )
17    {
18       // create Cylinder
19       Cylinder cylinder = new Cylinder( 5.7, 2.5, 12, 23 );
20       DecimalFormat precision2 = new DecimalFormat( "0.00" );
21
22       // get coordinates, radius and height
23       String output = "X coordinate is " + cylinder.getX() +
24          "\nY coordinate is " + cylinder.getY() +
25          "\nRadius is " + cylinder.getRadius() +
26          "\nHeight is " + cylinder.getHeight();
```

Fig. 9.15 Testing class **Cylinder** (part 1 of 2).

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```
27
28          // set coordinates, radius and height
29          cylinder.setHeight( 10 );
30          cylinder.setRadius( 4.25 );
31          cylinder.setPoint( 2, 2 );
32
33          // get String representation of Cylinder and calculate
34          // area and volume
35          output += "\n\nThe new location, radius " +
36             "and height of cylinder are\n" + cylinder +
37             "\nArea is " + precision2.format( cylinder.area() ) +
38             "\nVolume is " + precision2.format( cylinder.volume() );
39
40          JOptionPane.showMessageDialog( null, output,
41             "Demonstrating Class Cylinder",
42             JOptionPane.INFORMATION_MESSAGE );
43
44          System.exit( 0 );
45       }
46
47    }  // end class Test
```

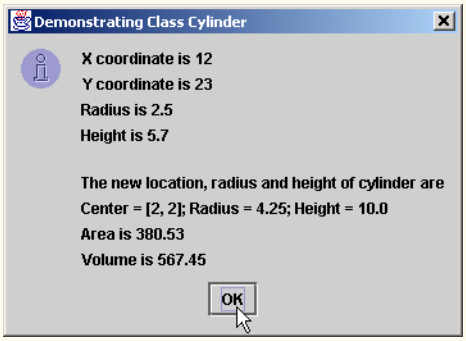

Fig. 9.15 Testing class **`Cylinder`** (part 2 of 2).

The series of examples in this section nicely demonstrates inheritance and defining and referencing **`protected`** instance variables. The reader should now be confident with the basics of inheritance. In the next several sections, we show how to program with inheritance hierarchies in a general manner, using polymorphism. Data abstraction, inheritance and polymorphism are the crux of object-oriented programming.

9.10 Introduction to Polymorphism

With *polymorphism,* it is possible to design and implement systems that are more easily *extensible.* Programs can be written to process generically—as superclass objects—objects of all existing classes in a hierarchy. Classes that do not exist during program development can be added with little or no modifications to the generic part of the program—as long as those classes are part of the hierarchy that is being processed generically. The only parts of

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a program that need modification are those parts that require direct knowledge of the particular class that is added to the hierarchy. We will study two substantial class hierarchies and will show how objects throughout those hierarchies are manipulated polymorphically.

9.11 Type Fields and `switch` Statements

One means of dealing with objects of many different types is to use a **`switch`** statement to take an appropriate action on each object, based on that object's type. For example, in a hierarchy of shapes in which each shape has a **`shapeType`** instance variable, a **`switch`** structure could determine which **`print`** method to call based on the object's **`shapeType`**.

There are many problems with using **`switch`** logic. The programmer might forget to make such a type test when one is warranted. The programmer might forget to test all possible cases in a **`switch`**. If a **`switch`**-based system is modified by adding new types, the programmer might forget to insert the new cases in existing **`switch`** statements. Every addition or deletion of a class demands that every **`switch`** statement in the system be modified; tracking these down can be time consuming and error prone.

As we will see, polymorphic programming can eliminate the need for **`switch`** logic. The programmer can use Java's polymorphism mechanism to perform the equivalent logic automatically, thus avoiding the kinds of errors typically associated with **`switch`** logic.

Testing and Debugging Tip 9.2

An interesting consequence of using polymorphism is that programs take on a simplified appearance. They contain less branching logic in favor of simpler sequential code. This simplification facilitates testing, debugging, and program maintenance.

9.12 Dynamic Method Binding

Suppose a set of shape classes such as **`Circle`**, **`Triangle`**, **`Rectangle`**, **`Square`**, are all derived from superclass **`Shape`**. In object-oriented programming, each of these classes might be endowed with the ability to draw itself. Each class has its own **`draw`** method, and the **`draw`** method implementation for each shape is quite different. When drawing a shape, whatever that shape may be, it would be nice to be able to treat all these shapes generically as objects of the superclass **`Shape`**. Then, to draw any shape, we could simply call method **`draw`** of superclass **`Shape`** and let the program determine dynamically (i.e., at execution time) which subclass **`draw`** method to use from the actual object's type.

To enable this kind of behavior, we declare **`draw`** in the superclass, and then we override **`draw`** in each of the subclasses to draw the appropriate shape.

Software Engineering Observation 9.16

When a subclass chooses not to redefine a method, the subclass simply inherits its immediate superclass's method definition.

If we use a superclass reference to refer to a subclass object and invoke the **`draw`** method, the program will choose the correct subclass's **`draw`** method dynamically (i.e., at execution time). This is called *dynamic method binding*. Dynamic method binding is an important mechanism for implementing polymorphic processing of objects and will be illustrated in the case studies later in this chapter

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9.13 `final` Methods and Classes

We saw in Chapter 7 that variables can be declared **`final`** to indicate that they cannot be modified after they are declared and that they must be initialized when they are declared. It is also possible to define methods and classes with the **`final`** modifier.

A method that is declared **`final`** cannot be overridden in a subclass. Methods that are declared **`static`** and methods that are declared **`private`** are implicitly **`final`**. Because a **`final`** method's definition can never change, the compiler can optimize the program by removing calls to **`final`** methods and replacing them with the expanded code of their definitions at each method call location—a technique known as *inlining the code*.

A class that is declared **`final`** cannot be a superclass (i.e., a class cannot inherit from a **`final`** class). All methods in a **`final`** class are implicitly **`final`**.

Performance Tip 9.2

*The compiler can decide to inline a **`final`** method call and will do so for small, simple **`final`** methods. Inlining does not violate encapsulation or information hiding (but does improve performance because it eliminates the overhead of making a method call).*

Software Engineering Observation 9.17

*A class declared **`final`** cannot be extended, and every method in it is implicitly **`final`**.*

Software Engineering Observation 9.18

*In the Java API, the vast majority of the thousands of classes are not declared **`final`**. This enables inheritance and polymorphic processing—the fundamental capabilities of object-oriented programming. However, in some cases it is important to declare classes **`final`**—typically for security[1] or performance reasons.*

9.14 Abstract Superclasses and Concrete Classes

When we think of a class as a type, we assume that objects of that type will be instantiated. However, there are cases in which it is useful to define classes for which the programmer never intends to instantiate any objects. Such classes are called *abstract classes.* Because these are used as superclasses in inheritance situations, we will normally refer to them as *abstract superclasses.* No objects of abstract superclasses can be instantiated.

The sole purpose of an abstract class is to provide an appropriate superclass from which other classes may inherit interface and/or implementation (we will see examples of each shortly). Classes from which objects can be instantiated are called *concrete classes.*

1. Class **`String`** is an example of a **`final`** class. This class cannot be extended, so programs that use **`String`**s can rely on the functionality of **`String`** objects as specified in the Java API. Making the class **`final`** also prevents programmers from creating subclasses that might bypass security restrictions. For example, when a Java program attempts to open a file on your computer, the program supplies a **`String`** representing the name of the file. In many cases, opening a file is subject to security restrictions. If it were possible to create a subclass of **`String`**, that subclass might be implemented in a manner that enables it to specify one **`String`** to pass a security or permissions test, then specify a different name when the program actually opens the file. For more information on final classes and methods visit: **`java.sun.com/docs/books/tutorial/java/javaOO/final.html`** [*Note*: **`String`**s are covered in detail in Chapter 10 and file processing is covered in detail in Chapter 16.]

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We could have an abstract superclass **TwoDimensionalObject** and derive concrete classes, such as **Square**, **Circle**, **Triangle**. We could also have an abstract superclass **ThreeDimensionalObject** and derive such concrete classes as **Cube**, **Sphere** and **Cylinder**. Abstract superclasses are too generic to define real objects; we need to be more specific before we can think of instantiating objects. For example, if someone tells you to "draw the shape," what shape would you draw? Concrete classes provide the specifics that make it reasonable to instantiate objects.

A class is made abstract by declaring it with keyword **abstract**. A hierarchy does not need to contain any **abstract** classes, but, as we will see, many good object-oriented systems have class hierarchies headed by **abstract** superclasses. In some cases, **abstract** classes constitute the top few levels of the hierarchy. A good example of this is the shape hierarchy in Fig. 9.3. The hierarchy begins with **abstract** superclass **Shape**. On the next level down we have two more **abstract** superclasses, namely **TwoDimensionalShape** and **ThreeDimensionalShape**. The next level down would start defining concrete classes for such two-dimensional shapes as **Circle** and **Square** and for such three-dimensional shapes as **Sphere** and **Cube**.

9.15 Polymorphism Examples

Here is an example of polymorphism. If class **Rectangle** is derived from class **Quadrilateral**, then a **Rectangle** object *is a* more specific version of a **Quadrilateral** object. An operation (such as calculating the perimeter or the area) that can be performed on an object of class **Quadrilateral** can also be performed on an object of class **Rectangle**. Such operations can also be performed on other "kinds of" **Quadrilateral**s, such as **Square**s, **Parallelogram**s and **Trapezoid**s. When a request is made through a superclass reference to use a method, Java chooses the correct overridden method polymorphically in the appropriate subclass associated with the object.

Here is another example of polymorphism. Suppose we have a video game that manipulates objects of many varieties, including objects of class **Martian**, **Venutian**, **Plutonian**, **SpaceShip**, **LaserBeam** and the like. Each of these classes extends a common superclass, **GamePiece**, that contains a method called **drawYourself**. This method is defined by each subclass. A Java screen manager program would simply maintain some kind of collection (such as a **GamePiece** array) of references to objects of these various classes. To refresh the screen periodically, the screen manager would simply send each object the same message, namely **drawYourself**. Each object would respond in its own unique way. A **Martian** object would draw itself with the appropriate number of antennae. A **SpaceShip** object would draw itself bright and silvery. A **LaserBeam** object would draw itself as a bright red beam across the screen. Thus, the same message sent to a variety of objects would have "many forms" of results—hence the term *polymorphism.*

Such a polymorphic screen manager makes it especially easy to add new types of objects to a system with minimal impact. Suppose we want to add **Mercurian**s to our video game. We certainly have to build a new class **Mercurian** that extends **GamePiece** and provides its own definition of the **drawYourself** method. Then, when objects of class **Mercurian** appear in the collection, the screen manager need not be modified. It simply sends the message **drawYourself** to every object in the collection

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regardless of the object's type, so the new **Mercurian** objects just "fit right in." Thus, with polymorphism, new types of objects not even envisioned when a system is created can be added without modifications to the system (other than the new class itself, of course).

Through the use of polymorphism, one method call can cause different actions to occur, depending on the type of the object receiving the call. This gives the programmer tremendous expressive capability. We will see examples of the power of polymorphism in the next several sections.

Software Engineering Observation 9.19

With polymorphism, the programmer can deal in generalities and let the execution-time environment concern itself with the specifics. The programmer can command a wide variety of objects to behave in manners appropriate to those objects without even knowing the types of those objects.

Software Engineering Observation 9.20

Polymorphism promotes extensibility: Software written to invoke polymorphic behavior is written independent of the types of the objects to which messages (i.e., method calls) are sent. Thus, new types of objects that can respond to existing messages can be added into such a system without modifying the base system.

Software Engineering Observation 9.21

*If a method is declared **final**, it cannot be overridden in subclasses, so method calls may not be sent polymorphically to objects of those subclasses. The method call may still be sent to subclasses, but they will all respond identically rather than polymorphically.*

Software Engineering Observation 9.22

*An **abstract** class defines a common interface for the various members of a class hierarchy. The **abstract** class contains methods that will be defined in the subclasses. All classes in the hierarchy can use this same interface through polymorphism.*

Although we cannot instantiate objects of **abstract** superclasses, we *can* declare references to **abstract** superclasses. Such references can be used to enable polymorphic manipulations of subclass objects when such objects are instantiated from concrete classes.

Let us consider more applications of polymorphism. A screen manager needs to display a variety of objects, including new types of objects that will be added to the system even after the screen manager is written. The system may need to display various shapes (the superclass is **Shape**), such as **Circle**, **Triangle** and **Rectangle**. Each shape class is derived from superclass **Shape**. The screen manager uses superclass **Shape** references to manage the objects to be displayed. To draw any object (regardless of the level at which that object appears in the inheritance hierarchy), the screen manager uses a superclass reference to the object and simply sends a **draw** message to the object. Method **draw** has been declared **abstract** in superclass **Shape** and has been overridden in each of the subclasses. Each **Shape** object knows how to draw itself. The screen manager does not have to worry about what type each object is or whether the screen manager has seen objects of that type before—the screen manager simply tells each object to **draw** itself.

Polymorphism is particularly effective for implementing layered software systems. In operating systems, for example, each type of physical device could operate quite differently from the others. Even so, commands to *read* or *write* data from and to devices can have a

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certain uniformity. The *write* message sent to a device-driver object needs to be interpreted specifically in the context of that device driver and how that device driver manipulates devices of a specific type. However, the *write* call itself is really no different from the *write* to any other device in the system—simply place some number of bytes from memory onto that device. An object-oriented operating system might use an **abstract** superclass to provide an interface appropriate for all device drivers. Then, through inheritance from that **abstract** superclass, subclasses are formed that all operate similarly. The capabilities (i.e., the **public** interface) offered by the device drivers are provided as **abstract** methods in the **abstract** superclass. The implementations of these **abstract** methods are provided in the subclasses that correspond to the specific types of device drivers.

It is common in object-oriented programming to define an *iterator class* that can walk through all the objects in a collection (such as an array). If you want to print a list of objects in a linked list, for example, an iterator object can be instantiated that will return the next element of the linked list each time the iterator is called. Iterators are commonly used in polymorphic programming to walk through an array or a linked list of objects from various levels of a hierarchy. The references in such a list would all be superclass references (see Chapter 19, Data Structures, for more on linked lists). A list of objects of superclass class **TwoDimensionalShape** could contain objects from the classes **Square**, **Circle**, **Triangle** and so on. Sending a **draw** message to each object in the list would, using polymorphism, draw the correct picture on the screen.

9.16 Case Study: A Payroll System Using Polymorphism

Let us use **abstract** classes, **abstract** methods and polymorphism to perform payroll calculations based on the type of employee (Fig. 9.16). We use an **abstract** superclass **Employee**. The subclasses of **Employee** are **Boss** (Fig. 9.17)—paid a fixed weekly salary regardless of the number of hours worked, **CommissionWorker** (Fig. 9.18)—paid a flat base salary plus a percentage of sales, **PieceWorker** (Fig. 9.19)—paid by the number of items produced and **HourlyWorker** (Fig. 9.20)—paid by the hour and receives overtime pay. Each subclass of **Employee** has been declared **final**, because we do not intend to inherit from them again.

An **earnings** method call certainly applies generically to all employees. But the way each person's earnings are calculated depends on the class of the employee, and these classes are all derived from the superclass **Employee**. So **earnings** is declared **abstract** in superclass **Employee** and appropriate implementations of **earnings** are provided for each of the subclasses. Then, to calculate any employee's earnings, the program simply uses a superclass reference to that employee's object and invokes the **earnings** method. In a real payroll system, the various **Employee** objects might be referenced by individual elements in an array of **Employee** references. The program would simply walk through the array one element at a time, using the **Employee** references to invoke the **earnings** method of each object.

Software Engineering Observation 9.23

*If a subclass is derived from a superclass with an **abstract** method, and if no definition is supplied in the subclass for that **abstract** method (i.e., if that method is not overridden in the subclass), that method remains **abstract** in the subclass. Consequently, the subclass is also an **abstract** class and must be explicitly declared as an **abstract** class.*

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Software Engineering Observation 9.24

The ability to declare an **`abstract`** *method gives the class designer considerable power over how subclasses will be implemented in a class hierarchy. Any new class that wants to inherit from this class is forced to override the* **`abstract`** *method (either directly or by inheriting from a class that has overridden the method). Otherwise, that new class will contain an* **`abstract`** *method and thus be an* **`abstract`** *class, unable to instantiate objects.*

Software Engineering Observation 9.25

An **`abstract`** *can still have instance data and non***`abstract`** *methods subject to the normal rules of inheritance by subclasses. An* **`abstract`** *class can also have constructors.*

Common Programming Error 9.7

Attempting to instantiate an object of an **`abstract`** *class (i.e., a class that contains one or more* **`abstract`** *methods) is a syntax error.*

Common Programming Error 9.8

It is a syntax error if a class with one or more **`abstract`** *methods is not explicitly declared* **`abstract`**.

Let us consider the **`Employee`** class (Fig. 9.16). The **`public`** methods include a constructor that takes the first name and last name as arguments; a **`getFirstName`** method that returns the first name; a **`getLastName`** method that returns the last name; a **`toString`** method that returns the first name and last name separated by a space; and an **`abstract`** method—**`earnings`**. Why is this method **`abstract`**? The answer is that it does not make sense to provide an implementation of this method in the **`Employee`** class. We cannot calculate the earnings for a generic employee—we must first know *what kind of* employee it is. By making this method **`abstract`** we are indicating that we will provide an implementation in each concrete subclass, but not in the superclass itself.

```
1  // Fig. 9.16: Employee.java
2  // Abstract base class Employee.
3
4  public abstract class Employee {
5     private String firstName;
6     private String lastName;
7
8     // constructor
9     public Employee( String first, String last )
10    {
11       firstName = first;
12       lastName = last;
13    }
14
15    // get first name
16    public String getFirstName()
17    {
18       return firstName;
19    }
20
```

Fig. 9.16 **`Employee abstract`** superclass (part 1 of 2).

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```
21      // get last name
22      public String getLastName()
23      {
24         return lastName;
25      }
26
27      public String toString()
28      {
29         return firstName + ' ' + lastName;
30      }
31
32      // Abstract method that must be implemented for each
33      // derived class of Employee from which objects
34      // are instantiated.
35      public abstract double earnings();
36
37   }  // end class Employee
```

Fig. 9.16 **Employee abstract** superclass (part 2 of 2).

Class **Boss** (Fig. 9.17) is derived from **Employee**. The **public** methods include a constructor that takes a first name, a last name and a weekly salary as arguments and passes the first name and last name to the **Employee** constructor to initialize the **firstName** and **lastName** members of the superclass part of the subclass object. Other **public** methods include a **setWeeklySalary** method to assign a new value to **private** instance variable **weeklySalary**; an **earnings** method defining how to calculate a **Boss**'s earnings; and a **toString** method that forms a **String** containing the type of the employee (i.e., **"Boss: "**) followed by the boss's name.

```
1   // Fig. 9.17: Boss.java
2   // Boss class derived from Employee.
3
4   public final class Boss extends Employee {
5      private double weeklySalary;
6
7      // constructor for class Boss
8      public Boss( String first, String last, double salary )
9      {
10        super( first, last );  // call superclass constructor
11        setWeeklySalary( salary );
12     }
13
14     // set Boss's salary
15     public void setWeeklySalary( double salary )
16     {
17        weeklySalary = ( salary > 0 ? salary : 0 );
18     }
19
```

Fig. 9.17 **Boss** extends **abstract** class **Employee**.

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```
20     // get Boss's pay
21     public double earnings()
22     {
23        return weeklySalary;
24     }
25
26     // get String representation of Boss's name
27     public String toString()
28     {
29        return "Boss: " + super.toString();
30     }
31
32  }  // end class Boss
```

Fig. 9.17 **Boss** extends **abstract** class **Employee**.

Class **CommissionWorker** (Fig. 9.18) is derived from **Employee**. The **public** methods include a constructor that takes a first name, a last name, a salary, a commission and a quantity of items sold as arguments and passes the first name and last name to the **Employee** constructor; *set* methods to assign new values to instance variables **salary**, **commission** and **quantity**; an **earnings** method to calculate a **CommissionWorker**'s earnings; and a **toString** method that forms a **String** containing the employee type (i.e., **"Commission worker: "**) followed by the worker's name.

```
1  // Fig. 9.18: CommissionWorker.java
2  // CommissionWorker class derived from Employee
3
4  public final class CommissionWorker extends Employee {
5     private double salary;       // base salary per week
6     private double commission;   // amount per item sold
7     private int quantity;        // total items sold for week
8
9     // constructor for class CommissionWorker
10    public CommissionWorker( String first, String last,
11       double salary, double commission, int quantity )
12    {
13       super( first, last );  // call superclass constructor
14       setSalary( salary );
15       setCommission( commission );
16       setQuantity( quantity );
17    }
18
19    // set CommissionWorker's weekly base salary
20    public void setSalary( double weeklySalary )
21    {
22       salary = ( weeklySalary > 0 ? weeklySalary : 0 );
23    }
24
```

Fig. 9.18 **CommissionWorker** extends **abstract** class **Employee** (part 1 of 2).

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```
25     // set CommissionWorker's commission
26     public void setCommission( double itemCommission )
27     {
28        commission = ( itemCommission > 0 ? itemCommission : 0 );
29     }
30
31     // set CommissionWorker's quantity sold
32     public void setQuantity( int totalSold )
33     {
34        quantity = ( totalSold > 0 ? totalSold : 0 );
35     }
36
37     // determine CommissionWorker's earnings
38     public double earnings()
39     {
40        return salary + commission * quantity;
41     }
42
43     // get String representation of CommissionWorker's name
44     public String toString()
45     {
46        return "Commission worker: " + super.toString();
47     }
48
49  }  // end class CommissionWorker
```

Fig. 9.18 **CommissionWorker** extends **abstract** class **Employee** (part 2 of 2).

Class **PieceWorker** (Fig. 9.19) is derived from **Employee**. The **public** methods include a constructor that takes a first name, a last name, a wage per piece and a quantity of items produced as arguments and passes the first name and last name to the **Employee** constructor; *set* methods to assign new values to instance variables **wagePerPiece** and **quantity**; an **earnings** method defining how to calculate a **PieceWorker**'s earnings; and a **toString** method that forms a **String** containing the type of the employee (i.e., **"Piece worker: "**) followed by the pieceworker's name.

```
1  // Fig. 9.19: PieceWorker.java
2  // PieceWorker class derived from Employee
3
4  public final class PieceWorker extends Employee {
5     private double wagePerPiece; // wage per piece output
6     private int quantity;        // output for week
7
8     // constructor for class PieceWorker
9     public PieceWorker( String first, String last,
10       double wage, int numberOfItems )
11    {
12       super( first, last );  // call superclass constructor
13       setWage( wage );
14       setQuantity( numberOfItems);
15    }
```

Fig. 9.19 **PieceWorker** extends **abstract** class **Employee** (part 1 of 2).

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```
16
17    // set PieceWorker's wage
18    public void setWage( double wage )
19    {
20       wagePerPiece = ( wage > 0 ? wage : 0 );
21    }
22
23    // set number of items output
24    public void setQuantity( int numberOfItems )
25    {
26       quantity = ( numberOfItems > 0 ? numberOfItems : 0 );
27    }
28
29    // determine PieceWorker's earnings
30    public double earnings()
31    {
32       return quantity * wagePerPiece;
33    }
34
35    public String toString()
36    {
37       return "Piece worker: " + super.toString();
38    }
39
40 }  // end class PieceWorker
```

Fig. 9.19 **PieceWorker** extends **abstract** class **Employee** (part 2 of 2).

Class **HourlyWorker** (Fig. 9.20) is derived from **Employee**. The **public** methods include a constructor that takes a first name, a last name, a wage and the number of hours worked as arguments and passes the first name and last name to the **Employee** constructor; *set* methods to assign new values to instance variables **wage** and **hours**; an **earnings** method defining how to calculate an **HourlyWorker**'s earnings; and a **toString** method that forms a **String** containing the type of the employee (i.e., **"Hourly worker: "**) followed by the hourly worker's name.

```
1  // Fig. 9.20: HourlyWorker.java
2  // Definition of class HourlyWorker
3
4  public final class HourlyWorker extends Employee {
5     private double wage;   // wage per hour
6     private double hours;  // hours worked for week
7
8     // constructor for class HourlyWorker
9     public HourlyWorker( String first, String last,
10       double wagePerHour, double hoursWorked )
11    {
12       super( first, last );   // call superclass constructor
13       setWage( wagePerHour );
14       setHours( hoursWorked );
15    }
```

Fig. 9.20 **HourlyWorker** extends **abstract** class **Employee** (part 1 of 2).

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```
16
17       // Set the wage
18       public void setWage( double wagePerHour )
19       {
20          wage = ( wagePerHour > 0 ? wagePerHour : 0 );
21       }
22
23       // Set the hours worked
24       public void setHours( double hoursWorked )
25       {
26          hours = ( hoursWorked >= 0 && hoursWorked < 168 ?
27             hoursWorked : 0 );
28       }
29
30       // Get the HourlyWorker's pay
31       public double earnings() { return wage * hours; }
32
33       public String toString()
34       {
35          return "Hourly worker: " + super.toString();
36       }
37
38    }  // end class HourlyWorker
```

Fig. 9.20 **HourlyWorker** extends **abstract** class **Employee** (part 2 of 2).

Method **main** of the **Test** application (Fig. 9.21) begins by declaring **Employee** reference, **ref**. Each of the types of **Employee**s is handled similarly in **main**, so we will discuss only the case in which **main** deals with a **Boss** object.

```
1  // Fig. 9.21: Test.java
2  // Driver for Employee hierarchy
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 public class Test {
11
12    // test Employee hierarchy
13    public static void main( String args[] )
14    {
15       Employee employee;  // superclass reference
16       String output = "";
17
18       Boss boss = new Boss( "John", "Smith", 800.0 );
19
```

Fig. 9.21 Testing the **Employee** class hierarchy using an **abstract** superclass.

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```
1         CommissionWorker commisionWorker =
2            new CommissionWorker(
3               "Sue", "Jones", 400.0, 3.0, 150 );
4
5         PieceWorker pieceWorker =
6            new PieceWorker( "Bob", "Lewis", 2.5, 200 );
7
8         HourlyWorker hourlyWorker =
9            new HourlyWorker( "Karen", "Price", 13.75, 40 );
10
11        DecimalFormat precision2 = new DecimalFormat( "0.00" );
12
13        // Employee reference to a Boss
14        employee = boss;
15
16        output += employee.toString() + " earned $" +
17           precision2.format( employee.earnings() ) + "\n" +
18           boss.toString() + " earned $" +
19           precision2.format( boss.earnings() ) + "\n";
20
21        // Employee reference to a CommissionWorker
22        employee = commissionWorker;
23
24        output += employee.toString() + " earned $" +
25           precision2.format( employee.earnings() ) + "\n" +
26           commissionWorker.toString() + " earned $" +
27           precision2.format(
28              commissionWorker.earnings() ) + "\n";
29
30        // Employee reference to a PieceWorker
31        employee = pieceWorker;
32
33        output += employee.toString() + " earned $" +
34           precision2.format( employee.earnings() ) + "\n" +
35           pieceWorker.toString() + " earned $" +
36           precision2.format( pieceWorker.earnings() ) + "\n";
37
38        // Employee reference to an HourlyWorker
39        employee = hourlyWorker;
40
41        output += employee.toString() + " earned $" +
42           precision2.format( employee.earnings() ) + "\n" +
43           hourlyWorker.toString() + " earned $" +
44           precision2.format( hourlyWorker.earnings() ) + "\n";
45
46        JOptionPane.showMessageDialog( null, output,
47           "Demonstrating Polymorphism",
48           JOptionPane.INFORMATION_MESSAGE );
49
50        System.exit( 0 );
51     }
52
53  }  // end class Test
```

Fig. 9.21 Testing the **Employee** class hierarchy using an **abstract** superclass.

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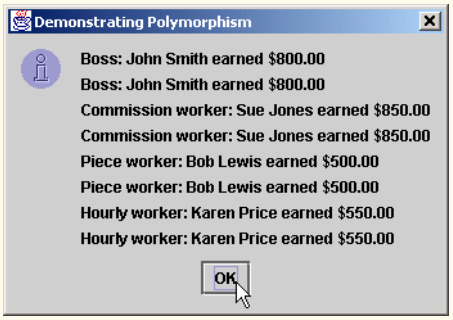

Fig. 9.21 Testing the **Employee** class hierarchy using an **abstract** superclass.

Line 18 instantiates subclass object class **Boss** and provides various constructor arguments, including a first name, a last name and a fixed weekly salary. The new object is assigned to **Boss** reference **boss**.

Line 33 assigns to superclass **Employee** reference **employee** a reference to the subclass **Boss** object to which **boss** refers. This is precisely what we must do to effect polymorphic behavior.

The method call in line 35 invokes the **toString** method of the object referenced by **employee**. The system determines that the referenced object is a **Boss** and invokes subclass **Boss**'s **toString** method—again, polymorphic behavior. This method call is an example of dynamic method binding—the decision as to what method to invoke is deferred until execution time.

The method call in line 36 invokes the **earnings** method of the object to which **employee** refers. The system determines that the object is a **Boss** and invokes the subclass **Boss**'s **earnings** method rather than the superclass's **earnings** method. This is also an example of dynamic method binding.

The method call in line 37 explicitly invokes the **Boss** version of method **toString** by following reference **boss** with the dot operator. We included line 37 for comparison purposes to ensure that the dynamically bound method invoked with **employee.toString()** was indeed the proper method.

The method call in line 38 explicitly invokes the **Boss** version of method **earnings** by using the dot operator with the specific **Boss** reference **boss**. This call is also included for comparison purposes to ensure that the dynamically bound method invoked with **employee.earnings()** was indeed the proper method.

To prove that the superclass reference **employee** can be used to invoke **toString** and **earnings** for the other types of employees, lines 41, 50 and 58 each assign a different type of employee object (**CommissionWorker**, **PieceWorker** and **HourlyWorker**, respectively) to the superclass reference **employee**; then the two methods are called after each assignment to show that Java is always capable of determining the type of the referenced object before invoking a method.

9.17 New Classes and Dynamic Binding

Polymorphism certainly works nicely when all possible classes are known in advance. But it also works when new kinds of classes are added to systems.

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New classes are accommodated by dynamic method binding (also called *late binding*). An object's type need not be known at compile time for a polymorphic call to be compiled. At execution time, the call is matched with the method of the called object.

A screen manager program can now handle (without recompilation) new types of display objects as they are added to the system. The **draw** method call remains the same. The new objects themselves each contain a **draw** method implementing the actual drawing capabilities. This makes it easy to add new capabilities to systems with minimal impact. It also promotes software reuse.

Performance Tip 9.3

The kinds of polymorphic manipulations made possible with dynamic binding can also be accomplished by using hand-coded **switch** *logic based on type fields in objects. The polymorphic code generated by the Java compiler runs with performance comparable to that of efficiently coded* **switch** *logic.*

Software Engineering Observation 9.26

Java provides mechanisms for loading classes into a program dynamically to enhance the functionality of an executing program. In particular, **static** *method* **forName** *of class* **Class** *(package* **java.lang***) can be used to load a class definition, then create new objects of that class for use in a program. This concept is beyond the scope of this book. For more information, see the online API documentation for* **Class***.*

9.18 Case Study: Inheriting Interface and Implementation

Our next example (Fig. 9.22–Fig. 9.26) reexamines the **Point**, **Circle**, **Cylinder** hierarchy, except that we now head the hierarchy with **abstract** superclass **Shape** (Fig. 9.22). This hierarchy mechanically demonstrates the power of polymorphism. In the exercises, we explore a more realistic hierarchy of shapes.

Shape contains **abstract** method **getName**, so **Shape** must be declared an **abstract** superclass. **Shape** contains two other methods, **area** and **volume**, each of which has an implementation that returns zero by default. **Point** inherits these implementations from **Shape**. This makes sense because both the area and volume of a point are zero. **Circle** inherits the **volume** method from **Point**, but **Circle** provides its own implementation for the **area** method. **Cylinder** provides its own implementations for both the **area** (interpreted as the surface area of the cylinder) and **volume** methods.

In this example, class **Shape** is used to define a set of methods that all **Shape**s in our hierarchy have in common. Defining these methods in class **Shape** enables us to generically call these methods through a **Shape** reference. Remember, the only methods that can be called through any reference are those **public** methods defined in the reference's declared class type and any **public** methods inherited into that class. Thus, we can call **Object** and **Shape** methods through a **Shape** reference.

Note that although **Shape** is an **abstract** superclass, it still contains implementations of methods **area** and **volume**, and these implementations are inheritable. The **Shape** class provides an inheritable interface (set of services) in the form of three methods that all classes of the hierarchy will contain. The **Shape** class also provides some implementations that subclasses in the first few levels of the hierarchy will use.

This case study emphasizes that a subclass can inherit interface and/or implementation from a superclass.

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Software Engineering Observation 9.27

Hierarchies designed for implementation inheritance tend to have their functionality high in the hierarchy—each new subclass inherits one or more methods that were defined in a superclass and uses the superclass definitions.

Software Engineering Observation 9.28

Hierarchies designed for interface inheritance tend to have their functionality lower in the hierarchy—a superclass specifies one or more methods that should be called identically for each object in the hierarchy (i.e., they have the same signature), but the individual subclasses provide their own implementations of the method(s).

Superclass **Shape** (Fig. 9.22) extends **Object**, consists of three **public** methods and does not contain any data (although it could). Method **getName** is **abstract**, so it is overridden in each of the subclasses. Methods **area** and **volume** are defined to return **0.0**. These methods are overridden in subclasses when it is appropriate for those classes to have a different **area** calculation (classes **Circle** and **Cylinder**) and/or a different **volume** calculation (class **Cylinder**).

Class **Point** (Fig. 9.23) is derived from **Shape**. A **Point** has an area of 0.0 and a volume of 0.0, so the superclass methods **area** and **volume** are not overridden here—they are inherited as defined in **Shape**. Other methods include **setPoint** to assign new **x** and **y** coordinates to a **Point** and **getX** and **getY** to return the **x** and **y** coordinates of a **Point**. Method **getName** is an implementation of the **abstract** method in the superclass. If this method were not defined, class **Point** would be an abstract class.

```
1  // Fig. 9.22: Shape.java
2  // Definition of abstract base class Shape
3
4  public abstract class Shape extends Object {
5
6     // return shape's area
7     public double area()
8     {
9        return 0.0;
10    }
11
12    // return shape's volume
13    public double volume()
14    {
15       return 0.0;
16    }
17
18    // abstract method must be defined by concrete subclasses
19    // to return appropriate shape name
20    public abstract String getName();
21
22 }  // end class Shape
```

Fig. 9.22 **Shape** abstract superclass for **Point**, **Circle**, **Cylinder** hierarchy.

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```
1  // Fig. 9.23: Point.java
2  // Definition of class Point
3
4  public class Point extends Shape {
5     protected int x, y; // coordinates of the Point
6
7     // no-argument constructor
8     public Point()
9     {
10       setPoint( 0, 0 );
11    }
12
13    // constructor
14    public Point( int xCoordinate, int yCoordinate )
15    {
16       setPoint( xCoordinate, yCoordinate );
17    }
18
19    // set x and y coordinates of Point
20    public void setPoint( int xCoordinate, int yCoordinate )
21    {
22       x = xCoordinate;
23       y = yCoordinate;
24    }
25
26    // get x coordinate
27    public int getX()
28    {
29       return x;
30    }
31
32    // get y coordinate
33    public int getY()
34    {
35       return y;
36    }
37
38    // convert point into String representation
39    public String toString()
40    {
41       return "[" + x + ", " + y + "]";
42    }
43
44    // return shape name
45    public String getName()
46    {
47       return "Point";
48    }
49
50 }  // end class Point
```

Fig. 9.23 **Point** subclass of abstract class **Shape**.

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Class **Circle** (Fig. 9.24) is derived from **Point**. A **Circle** has a volume of 0.0, so superclass method **volume** is not overridden—it is inherited from class **Point**, which inherited it from **Shape**. A **Circle** has an area different from that of a **Point**, so the **area** method is overridden. Method **getName** is an implementation of the **abstract** method in the superclass. If this method is not overridden here, the **Point** version of **getName** would be inherited. Other methods include **setRadius** to assign a new **radius** to a **Circle** and **getRadius** to return the **radius** of a **Circle**.

```
1  // Fig. 9.24: Circle.java
2  // Definition of class Circle
3
4  public class Circle extends Point {  // inherits from Point
5     protected double radius;
6
7     // no-argument constructor
8     public Circle()
9     {
10       // implicit call to superclass constructor here
11       setRadius( 0 );
12    }
13
14    // constructor
15    public Circle( double circleRadius, int xCoordinate,
16       int yCoordinate )
17    {
18       // call superclass constructor
19       super( xCoordinate, yCoordinate );
20
21       setRadius( circleRadius );
22    }
23
24    // set radius of Circle
25    public void setRadius( double circleRadius )
26    {
27       radius = ( circleRadius >= 0 ? circleRadius : 0 );
28    }
29
30    // get radius of Circle
31    public double getRadius()
32    {
33       return radius;
34    }
35
36    // calculate area of Circle
37    public double area()
38    {
39       return Math.PI * radius * radius;
40    }
41
```

Fig. 9.24 **Circle** subclass of **Point**—indirect subclass of **abstract** class **Shape** (part 1 of 2).

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```
42     // convert Circle to a String represention
43     public String toString()
44     {
45        return "Center = " + super.toString() +
46           "; Radius = " + radius;
47     }
48
49     // return shape name
50     public String getName()
51     {
52        return "Circle";
53     }
54
55  }  // end class Circle
```

Fig. 9.24 **Circle** subclass of **Point**—indirect subclass of **abstract** class **Shape** (part 2 of 2).

Software Engineering Observation 9.29

*A subclass always inherits the most recently defined version of each **public** and **protected** method from its direct and indirect superclasses.*

Class **Cylinder** (Fig. 9.25) is derived from **Circle**. A **Cylinder** has area and volume different from those of class **Circle**, so the **area** and **volume** methods are both overridden. Method **getName** is an implementation of the **abstract** method in the superclass. If this method had not been overridden here, the **Circle** version of **getName** would be inherited. Other methods include **setHeight** to assign a new **height** to a **Cylinder** and **getHeight** to return the **height** of a **Cylinder**.

```
1  // Fig. 9.25: Cylinder.java
2  // Definition of class Cylinder.
3
4  public class Cylinder extends Circle {
5     protected double height;  // height of Cylinder
6
7     // no-argument constructor
8     public Cylinder()
9     {
10       // implicit call to superclass constructor here
11       setHeight( 0 );
12    }
13
14    // constructor
15    public Cylinder( double cylinderHeight,
16       double cylinderRadius, int xCoordinate,
17       int yCoordinate )
18    {
19       // call superclass constructor
20       super( cylinderRadius, xCoordinate, yCoordinate );
```

Fig. 9.25 **Cylinder** subclass of **Circle**—indirect subclass of abstract class **Shape** (part 1 of 2).

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```
21
22          setHeight( cylinderHeight );
23       }
24
25       // set height of Cylinder
26       public void setHeight( double cylinderHeight )
27       {
28          height = ( cylinderHeight >= 0 ? cylinderHeight : 0 );
29       }
30
31       // get height of Cylinder
32       public double getHeight()
33       {
34          return height;
35       }
36
37       // calculate area of Cylinder (i.e., surface area)
38       public double area()
39       {
40          return 2 * super.area() + 2 * Math.PI * radius * height;
41       }
42
43       // calculate volume of Cylinder
44       public double volume()
45       {
46          return super.area() * height;
47       }
48
49       // convert Cylinder to a String representation
50       public String toString()
51       {
52          return super.toString() + "; Height = " + height;
53       }
54
55       // return shape name
56       public String getName()
57       {
58          return "Cylinder";
59       }
60
61    }  // end class Cylinder
```

Fig. 9.25 **Cylinder** subclass of **Circle**—indirect subclass of abstract class **Shape** (part 2 of 2).

Method **main** of class **Test** (Fig. 9.26) instantiates **Point** object **point**, **Circle** object **circle** and **Cylinder** object **cylinder** (lines 16–18). Next, array **arrayOfShapes** is instantiated (line 21). This array of superclass **Shape** references will refer to each subclass object instantiated. At line 24, the reference **point** is assigned to array element **arrayOfShapes[0]**. At line 27, the reference **circle** is assigned to array element **arrayOfShapes[1]**. At line 30, the reference **cylinder** is assigned to array element **arrayOfShapes[2]**. Now, each superclass **Shape** reference in the array refers to a subclass object of type **Point**, **Circle** or **Cylinder**.

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```
1  // Fig. 9.26: Test.java
2  // Class to test Shape, Point, Circle, Cylinder hierarchy
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 public class Test {
11
12    // test Shape hierarchy
13    public static void main( String args[] )
14    {
15       // create shapes
16       Point point = new Point( 7, 11 );
17       Circle circle = new Circle( 3.5, 22, 8 );
18       Cylinder cylinder = new Cylinder( 10, 3.3, 10, 10 );
19
20       // create Shape array
21       Shape arrayOfShapes[] = new Shape[ 3 ];
22
23       // aim arrayOfShapes[ 0 ] at subclass Point object
24       arrayOfShapes[ 0 ] = point;
25
26       // aim arrayOfShapes[ 1 ] at subclass Circle object
27       arrayOfShapes[ 1 ] = circle;
28
29       // aim arrayOfShapes[ 2 ] at subclass Cylinder object
30       arrayOfShapes[ 2 ] = cylinder;
31
32       // get name and String representation of each shape
33       String output =
34          point.getName() + ": " + point.toString() + "\n" +
35          circle.getName() + ": " + circle.toString() + "\n" +
36          cylinder.getName() + ": " + cylinder.toString();
37
38       DecimalFormat precision2 = new DecimalFormat( "0.00" );
39
40       // loop through arrayOfShapes and get name,
41       // area and volume of each shape in arrayOfShapes
42       for ( int i = 0; i < arrayOfShapes.length; i++ ) {
43          output += "\n\n" + arrayOfShapes[ i ].getName() +
44             ": " + arrayOfShapes[ i ].toString() +
45             "\nArea = " +
46             precision2.format( arrayOfShapes[ i ].area() ) +
47             "\nVolume = " +
48             precision2.format( arrayOfShapes[ i ].volume() );
49       }
50
51       JOptionPane.showMessageDialog( null, output,
52          "Demonstrating Polymorphism",
53          JOptionPane.INFORMATION_MESSAGE );
```

Fig. 9.26 **Shape**, **Point**, **Circle**, **Cylinder** hierarchy (part 1 of 2).

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```
54
55          System.exit( 0 );
56       }
57
58    }  // end class Test
```

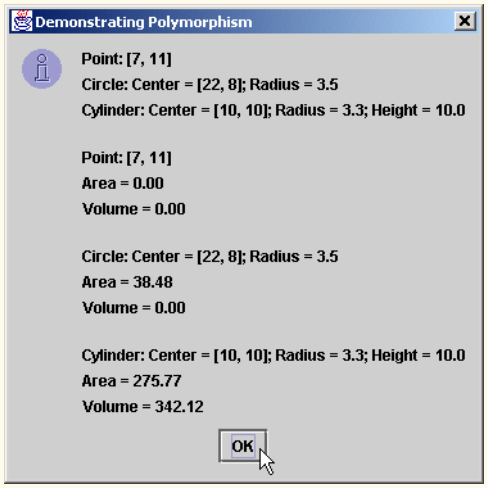

Fig. 9.26 **Shape**, **Point**, **Circle**, **Cylinder** hierarchy (part 2 of 2).

Lines 33 through 36 invoke methods **getName** and **toString** to illustrate that the objects are initialized correctly (as in the first three lines of the screen capture).

Next, the **for** structure at lines 42–49 walks through **arrayOfShapes**, and the following calls are made during each iteration of the loop:

```
arrayOfShapes[ i ].getName()
arrayOfShapes[ i ].toString()
arrayOfShapes[ i ].area()
arrayOfShapes[ i ].volume()
```

Each of these method calls is invoked on the object to which **arrayOfShapes[i]** currently refers. When the compiler looks at each of these calls, it is simply trying to determine whether a **Shape** reference (**arrayOfShapes[i]**) can be used to call these methods. For methods **getName**, **area** and **volume** the answer is yes, because each of these methods is defined in class **Shape**. For method **toString**, the compiler first looks at class **Shape** to determine that **toString** is not defined there, then the compiler proceeds to **Shape**'s superclass (**Object**) to determine whether **Shape** inherited a **toString** method that takes no arguments (as it did, because all **Object**s have a **toString** method).

The screen capture illustrates that all four methods are invoked properly based on the type of the referenced object. First, the string **"Point: "** and the coordinates of the object **point** (**arrayOfShapes[0]**) are output; the area and volume are both **0**. Next, the string **"Circle: "**, the coordinates of object **circle**, and the radius of object **circle** (**arrayOfShapes[1]**) are output; the area of **circle** is calculated and the volume is

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0. Finally, the string **"Cylinder: "**, the coordinates of object **cylinder**, the radius of object **cylinder** and the height of object **cylinder** (**arrayOfShapes[2]**) are output; the area of **cylinder** is calculated and the volume of **cylinder** is calculated. All the method calls to **getName**, **toString**, **area** and **volume** are resolved at run-time with dynamic binding.

9.19 Case Study: Creating and Using Interfaces

Our next example (Fig. 9.27–Fig. 9.31) reexamines the **Point**, **Circle**, **Cylinder** hierarchy one last time, replacing **abstract** superclass **Shape** with the interface **Shape** (Fig. 9.27). An interface definition begins with the keyword ***interface*** and contains a set of **public abstract** methods. Interfaces may also contain **public static final** data. To use an interface, a class must specify that it **implements** the interface and the class must define every method in the interface with the number of arguments and the return type specified in the interface definition. If the class leaves any method of the interface undefined, the class becomes an **abstract** class and must be declared **abstract** in the first line of its class definition. Implementing a interface is like signing a contract with the compiler that states, "I will define all the methods specified by the interface."

Common Programming Error 9.9

*Leaving a method of an **interface** undefined in a class that **implements** the interface results in a compile error indicating that the class must be declared **abstract**.*

Software Engineering Observation 9.30

*Declaring a **final** reference indicates that the reference always refers to the same object. However, this does not affect the object to which the reference refers—the object's data still can be modified.*

We started using the concept of an interface when we introduced GUI event handling in Chapter 6, "Methods." Recall that our applet class included **implements ActionListener** (an interface in package **java.awt.event**). The reason we were required to define **actionPerformed** in the applets with event handling is that **ActionListener** is an interface that specifies that **actionPerformed** must be defined. Interfaces are an important part of GUI event handling, as we will discuss in the next section.

An interface is typically used in place of an **abstract** class when there is no default implementation to inherit—i.e., no instance variables and no default method implementations. Like **public abstract** classes, **interface**s are typically **public** data types, so they are normally defined in files by themselves with the same name as the interface and the **.java** extension.

The definition of interface **Shape** begins in Fig. 9.27 at line 4. Interface **Shape** has **abstract** methods **area**, **volume** and **getName**. By coincidence, all three methods take no arguments. However, this is not a requirement of methods in an interface.

In Fig. 9.28, line 4 indicates that class **Point** extends class **Object** and implements interface **Shape**. Class **Point** provides definitions of all three methods in the interface. Method **area** is defined at lines 45–48. Method **volume** is defined at lines 51–54. Method **getName** is defined at lines 57–60. These three methods satisfy the implementation requirement for the three methods defined in the interface. We have fulfilled our contract with the compiler.

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```
1  // Fig. 9.27: Shape.java
2  // Definition of interface Shape
3
4  public interface Shape {
5
6     // calculate area
7     public abstract double area();
8
9     // calculate volume
10    public abstract double volume();
11
12    // return shape name
13    public abstract String getName();
14 }
```

Fig. 9.27 Point, circle, cylinder hierarchy with a **Shape** interface.

```
1  // Fig. 9.28: Point.java
2  // Definition of class Point
3
4  public class Point extends Object implements Shape {
5     protected int x, y; // coordinates of the Point
6
7     // no-argument constructor
8     public Point()
9     {
10       setPoint( 0, 0 );
11    }
12
13    // constructor
14    public Point( int xCoordinate, int yCoordinate )
15    {
16       setPoint( xCoordinate, yCoordinate );
17    }
18
19    // Set x and y coordinates of Point
20    public void setPoint( int xCoordinate, int yCoordinate )
21    {
22       x = xCoordinate;
23       y = yCoordinate;
24    }
25
26    // get x coordinate
27    public int getX()
28    {
29       return x;
30    }
31
```

Fig. 9.28 **Point** implementation of interface **Shape** (part 1 of 2).

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```
32      // get y coordinate
33      public int getY()
34      {
35         return y;
36      }
37
38      // convert point into String representation
39      public String toString()
40      {
41         return "[" + x + ", " + y + "]";
42      }
43
44      // calculate area
45      public double area()
46      {
47         return 0.0;
48      }
49
50      // calculate volume
51      public double volume()
52      {
53         return 0.0;
54      }
55
56      // return shape name
57      public String getName()
58      {
59         return "Point";
60      }
61
62   }  // end class Point
```

Fig. 9.28 **Point** implementation of interface **Shape** (part 2 of 2).

When a class implements an interface, the same *is a* relationship provided by inheritance applies. For example, class **Point** implements **Shape**. Therefore, a **Point** object *is a* **Shape**. In fact, objects of any class that extends **Point** are also **Shape** objects. Using this relationship, we have maintained the original definitions of class **Circle**, class **Cylinder** and application class **Test** from Section 9.18 (repoeated in Fig. 9.29–Fig. 9.31) to illustrate that an interface can be used instead of an **abstract** class to process **Shape**s polymorphically. Notice that the output for the program (Fig. 9.31) is identical to Fig. 9.22. Also, notice that **Object** method **toString** is called through a **Shape** interface reference (line 44).

Software Engineering Observation 9.31

*All methods of class **Object** can be called by using a reference of an interface data type—a reference refers to an object, and all objects have the methods defined by class **Object**.*

One benefit of using interfaces is that a class can implement as many interfaces as it needs in addition to extending a class. To implement more than one interface, simply provide a comma-separated list of interface names after keyword **implements** in the class definition. This is particularly useful in the GUI event-handling mechanism. A class that implements more than one event-listener interface (such as **ActionListener** in earlier

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examples) can process different types of GUI events, as we will see in Chapter 12 and Chapter 13.

```
1  // Fig. 9.29: Circle.java
2  // Definition of class Circle
3
4  public class Circle extends Point {  // inherits from Point
5     protected double radius;
6
7     // no-argument constructor
8     public Circle()
9     {
10       // implicit call to superclass constructor here
11       setRadius( 0 );
12    }
13
14    // constructor
15    public Circle( double circleRadius, int xCoordinate,
16       int yCoordinate )
17    {
18       // call superclass constructor
19       super( xCoordinate, yCoordinate );
20
21       setRadius( circleRadius );
22    }
23
24    // set radius of Circle
25    public void setRadius( double circleRadius )
26    {
27       radius = ( circleRadius >= 0 ? circleRadius : 0 );
28    }
29
30    // get radius of Circle
31    public double getRadius()
32    {
33       return radius;
34    }
35
36    // calculate area of Circle
37    public double area()
38    {
39       return Math.PI * radius * radius;
40    }
41
42    // convert Circle to a String representation
43    public String toString()
44    {
45       return "Center = " + super.toString() +
46          "; Radius = " + radius;
47    }
```

Fig. 9.29 **Circle** subclass of **Point**—indirect implementation of interface **Shape** (part 1 of 2).

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```
48
49     // return shape name
50     public String getName()
51     {
52        return "Circle";
53     }
54
55  }  // end class Circle
```

Fig. 9.29 **Circle** subclass of **Point**—indirect implementation of interface **Shape** (part 2 of 2).

```
1  // Fig. 9.30: Cylinder.java
2  // Definition of class Cylinder.
3
4  public class Cylinder extends Circle {
5     protected double height;  // height of Cylinder
6
7     // no-argument constructor
8     public Cylinder()
9     {
10       // implicit call to superclass constructor here
11       setHeight( 0 );
12    }
13
14    // constructor
15    public Cylinder( double cylinderHeight,
16       double cylinderRadius, int xCoordinate,
17       int yCoordinate )
18    {
19       // call superclass constructor
20       super( cylinderRadius, xCoordinate, yCoordinate );
21
22       setHeight( cylinderHeight );
23    }
24
25    // set height of Cylinder
26    public void setHeight( double cylinderHeight )
27    {
28       height = ( cylinderHeight >= 0 ? cylinderHeight : 0 );
29    }
30
31    // get height of Cylinder
32    public double getHeight()
33    {
34       return height;
35    }
36
37    // calculate area of Cylinder (i.e., surface area)
38    public double area()
39    {
```

Fig. 9.30 **Cylinder** subclass of **Circle**—indirect implementation of interface **Shape** (part 1 of 2).

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```
40          return 2 * super.area() + 2 * Math.PI * radius * height;
41       }
42
43       // calculate volume of Cylinder
44       public double volume()
45       {
46          return super.area() * height;
47       }
48
49       // convert Cylinder to a String representation
50       public String toString()
51       {
52          return super.toString() + "; Height = " + height;
53       }
54
55       // return shape name
56       public String getName()
57       {
58          return "Cylinder";
59       }
60
61    }  // end class Cylinder
```

Fig. 9.30 **Cylinder** subclass of **Circle**—indirect implementation of interface **Shape** (part 2 of 2).

```
1  // Fig. 9.31: Test.java
2  // Test Point, Circle, Cylinder hierarchy with interface Shape.
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // Java extension packages
8  import javax.swing.JOptionPane;
9
10 public class Test {
11
12    // test Shape hierarchy
13    public static void main( String args[] )
14    {
15       // create shapes
16       Point point = new Point( 7, 11 );
17       Circle circle = new Circle( 3.5, 22, 8 );
18       Cylinder cylinder = new Cylinder( 10, 3.3, 10, 10 );
19
20       // create Shape array
21       Shape arrayOfShapes[] = new Shape[ 3 ];
22
23       // aim arrayOfShapes[ 0 ] at subclass Point object
24       arrayOfShapes[ 0 ] = point;
25
```

Fig. 9.31 **Shape**, **Point**, **Circle**, **Cylinder** hierarchy (part 1 of 2).

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```
26          // aim arrayOfShapes[ 1 ] at subclass Circle object
27          arrayOfShapes[ 1 ] = circle;
28
29          // aim arrayOfShapes[ 2 ] at subclass Cylinder object
30          arrayOfShapes[ 2 ] = cylinder;
31
32          // get name and String representation of each shape
33          String output =
34             point.getName() + ": " + point.toString() + "\n" +
35             circle.getName() + ": " + circle.toString() + "\n" +
36             cylinder.getName() + ": " + cylinder.toString();
37
38          DecimalFormat precision2 = new DecimalFormat( "0.00" );
39
40          // loop through arrayOfShapes and get name,
41          // area and volume of each shape in arrayOfShapes
42          for ( int i = 0; i < arrayOfShapes.length; i++ ) {
43             output += "\n\n" + arrayOfShapes[ i ].getName() +
44                ": " + arrayOfShapes[ i ].toString() +
45                "\nArea = " +
46                precision2.format( arrayOfShapes[ i ].area() ) +
47                "\nVolume = " +
48                precision2.format( arrayOfShapes[ i ].volume() );
49          }
50
51          JOptionPane.showMessageDialog( null, output,
52             "Demonstrating Polymorphism",
53             JOptionPane.INFORMATION_MESSAGE );
54
55          System.exit( 0 );
56       }
57
58    }  // end class Test
```

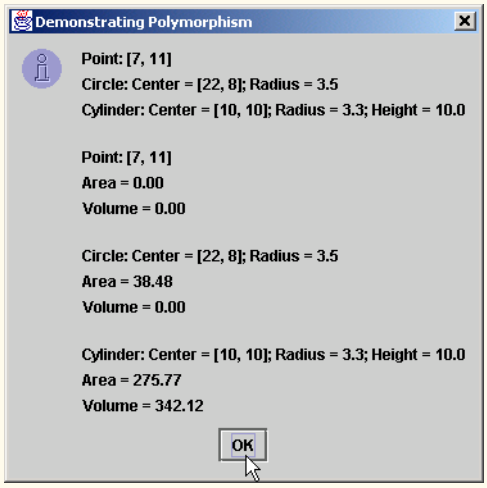

Fig. 9.31 **Shape**, **Point**, **Circle**, **Cylinder** hierarchy (part 2 of 2).

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Another use of interfaces is to define a set of constants that can be used in many class definitions. Consider interface **Constants**

```
public interface Constants {
   public static final int ONE = 1;
   public static final int TWO = 2;
   public static final int THREE = 3;
}
```

Classes that implement interface **Constants** can use **ONE**, **TWO** and **THREE** anywhere in the class definition. A class can even use these constants by importing the interface, then referring to each constant as **Constants.ONE**, **Constants.TWO** and **Constants.THREE**. There are no methods declared in this interface, so a class that implements the interface is not required to provide any method implementations.

9.20 Inner Class Definitions

All the class definitions discussed so far were defined at file scope. For example, if a file contained two classes, one class was not nested in the body of the other class. Java provides a facility called *inner classes*, in which classes can be defined inside other classes. Such classes can be complete class definitions or *anonymous inner class* definitions (classes without a name). Inner classes are used mainly in event handling. However, they have other benefits. For example, the implementation of the queue abstract data type discussed in Section 8.16.1 might use an inner class to represent the objects that store each item currently in the queue. Only the queue data structure requires knowledge of how the objects are stored internally, so the implementation can be hidden by defining an inner class as part of class **Queue**.

Inner classes frequently are used with GUI event handling, we take this opportunity not only to show you inner class definitions, but also to demonstrate an application that executes in its own window. After you complete this example, you will be able to use in your applications the GUI techniques shown only in applets so far.

To demonstrate an inner class definition, Fig. 9.33 uses a simplified version of the **Time3** class (renamed **Time** in Fig. 9.32) from Figure 8.8. Class **Time** provides a default constructor, the same *set/get* methods as Figure 8.8 and a **toString** method. Also, this program defines class **TimeTestWindow** as an application. The application executes in its own window. [*Note*: We do not discuss class Time here, because all its features were discussed in Chapter 8.]

```
1  // Fig. 9.32: Time.java
2  // Time class definition.
3
4  // Java core packages
5  import java.text.DecimalFormat;
6
7  // This class maintains the time in 24-hour format
8  public class Time extends Object {
9     private int hour;     // 0 - 23
10    private int minute;   // 0 - 59
11    private int second;   // 0 - 59
```

Fig. 9.32 **Time** class (part 1 of 3).

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```
12
13    // Time constructor initializes each instance variable
14    // to zero. Ensures that Time object starts in a
15    // consistent state.
16    public Time()
17    {
18       setTime( 0, 0, 0 );
19    }
20
21    // Set a new time value using universal time. Perform
22    // validity checks on the data. Set invalid values to zero.
23    public void setTime( int hour, int minute, int second )
24    {
25       setHour( hour );
26       setMinute( minute );
27       setSecond( second );
28    }
29
30    // validate and set hour
31    public void setHour( int h )
32    {
33       hour = ( ( h >= 0 && h < 24 ) ? h : 0 );
34    }
35
36    // validate and set minute
37    public void setMinute( int m )
38    {
39       minute = ( ( m >= 0 && m < 60 ) ? m : 0 );
40    }
41
42    // validate and set second
43    public void setSecond( int s )
44    {
45       second = ( ( s >= 0 && s < 60 ) ? s : 0 );
46    }
47
48    // get hour
49    public int getHour()
50    {
51       return hour;
52    }
53
54    // get minute
55    public int getMinute()
56    {
57       return minute;
58    }
59
60    // get second
61    public int getSecond()
62    {
63       return second;
64    }
```

Fig. 9.32 **Time** class (part 2 of 3).

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```
65
66     // convert to String in standard-time format
67     public String toString()
68     {
69        DecimalFormat twoDigits = new DecimalFormat( "00" );
70
71        return ( ( getHour() == 12 || getHour() == 0 ) ?
72           12 : getHour() % 12 ) + ":" +
73           twoDigits.format( getMinute() ) + ":" +
74           twoDigits.format( getSecond() ) +
75           ( getHour() < 12 ? " AM" : " PM" );
76     }
77
78  }  // end class Time
```

Fig. 9.32 **Time** class (part 3 of 3).

```
1  // Fig. 9.33: TimeTestWindow.java
2  // Demonstrating the Time class set and get methods
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class TimeTestWindow extends JFrame {
12    private Time time;
13    private JLabel hourLabel, minuteLabel, secondLabel;
14    private JTextField hourField, minuteField,
15       secondField, displayField;
16    private JButton exitButton;
17
18    // set up GUI
19    public TimeTestWindow()
20    {
21       super( "Inner Class Demonstration" );
22
23       time = new Time();
24
25       // create an instance of inner class ActionEventHandler
26       ActionEventHandler handler = new ActionEventHandler();
27
28       // set up GUI
29       Container container = getContentPane();
30       container.setLayout( new FlowLayout() );
31
32       hourLabel = new JLabel( "Set Hour" );
33       hourField = new JTextField( 10 );
34       hourField.addActionListener( handler );
```

Fig. 9.33 Demonstrating an inner class in a windowed application (part 1 of 4).

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```
35          container.add( hourLabel );
36          container.add( hourField );
37
38          minuteLabel = new JLabel( "Set minute" );
39          minuteField = new JTextField( 10 );
40          minuteField.addActionListener( handler );
41          container.add( minuteLabel );
42          container.add( minuteField );
43
44          secondLabel = new JLabel( "Set Second" );
45          secondField = new JTextField( 10 );
46          secondField.addActionListener( handler );
47          container.add( secondLabel );
48          container.add( secondField );
49
50          displayField = new JTextField( 30 );
51          displayField.setEditable( false );
52          container.add( displayField );
53
54          exitButton = new JButton( "Exit" );
55          exitButton.addActionListener( handler );
56          container.add( exitButton );
57
58       }  // end constructor
59
60       // display time in displayField
61       public void displayTime()
62       {
63          displayField.setText( "The time is: " + time );
64       }
65
66       // create TimeTestWindow and display it
67       public static void main( String args[] )
68       {
69          TimeTestWindow window = new TimeTestWindow();
70
71          window.setSize( 400, 140 );
72          window.setVisible( true );
73       }
74
75       // inner class definition for handling JTextField and
76       // JButton events
77       private class ActionEventHandler
78          implements ActionListener {
79
80          // method to handle action events
81          public void actionPerformed( ActionEvent event )
82          {
83             // user pressed exitButton
84             if ( event.getSource() == exitButton )
85                System.exit( 0 );   // terminate the application
86
```

Fig. 9.33 Demonstrating an inner class in a windowed application (part 2 of 4).

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```
87            // user pressed Enter key in hourField
88            else if ( event.getSource() == hourField ) {
89               time.setHour(
90                  Integer.parseInt( event.getActionCommand() ) );
91               hourField.setText( "" );
92            }
93
94            // user pressed Enter key in minuteField
95            else if ( event.getSource() == minuteField ) {
96               time.setMinute(
97                  Integer.parseInt( event.getActionCommand() ) );
98               minuteField.setText( "" );
99            }
100
101           // user pressed Enter key in secondField
102           else if ( event.getSource() == secondField ) {
103              time.setSecond(
104                 Integer.parseInt( event.getActionCommand() ) );
105              secondField.setText( "" );
106           }
107
108           displayTime();
109        }
110
111     }  // end inner class ActionEventHandler
112
113  }  // end class TimeTestWindow
```

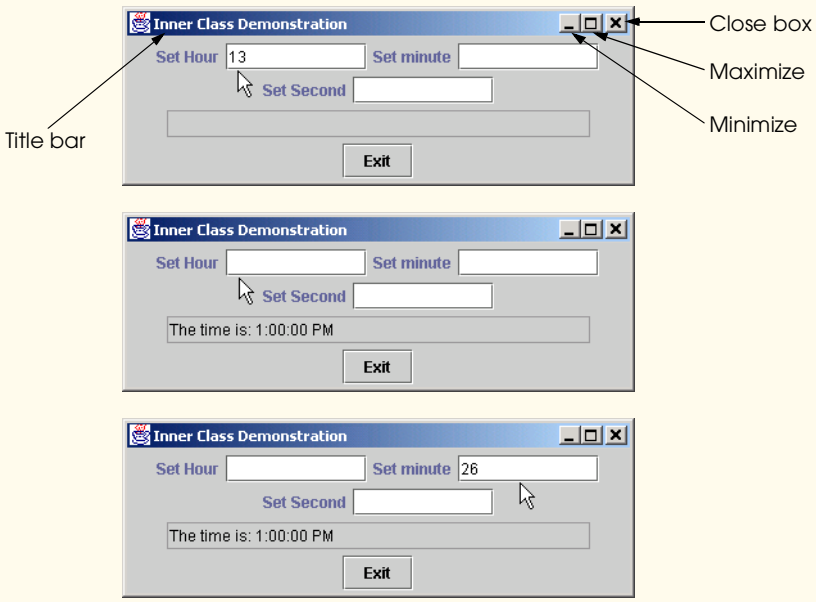

Fig. 9.33 Demonstrating an inner class in a windowed application (part 3 of 4).

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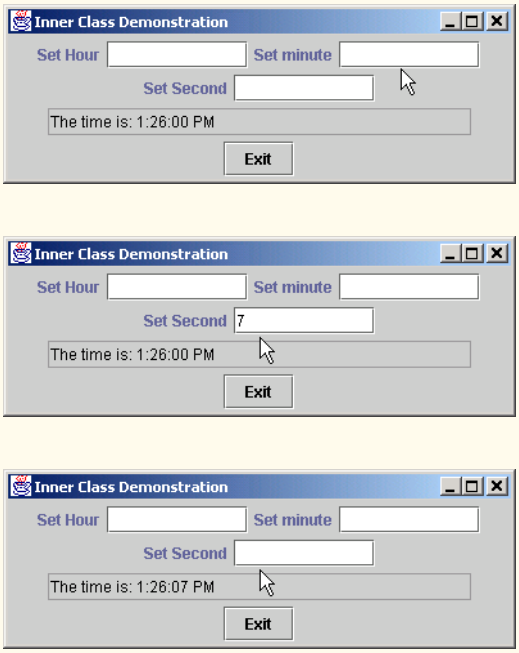

Fig. 9.33 Demonstrating an inner class in a windowed application (part 4 of 4).

In Fig. 9.33, line 11 indicates that class **`TimeTestWindow`** extends class ***`JFrame`*** (from package **`javax.swing`**) rather than class **`JApplet`** (as shown in Figure 8.8). Superclass **`JFrame`** provides the basic attributes and behaviors of a window—a *title bar* and buttons to *minimize*, *maximize* and *close* the window (all labeled in the first screen capture). Class **`TimeTestWindow`** uses the same GUI components as the applet of Fig. 8.8, except that the button (line 16) is now called **`exitButton`** and is used to terminate the application.

The **`init`** method of the applet has been replaced by a constructor (lines 19–54) to guarantee that the window's GUI components are created as the application begins executing. Method **`main`** (lines 67–73) defines a **`new`** object of class **`TimeTestWindow`** that results in a call to the constructor. Remember, **`init`** is a special method that is guaranteed to be called when an applet begins execution. However, this program is not an applet, so if we did define the **`init`** method, it would not be called automatically.

Several new features appear in the constructor. Line 21 calls the superclass **`JFrame`** constructor with the string **`"Inner Class Demonstration"`**. This string is displayed in the title bar of the window by class **`JFrame`**'s constructor. Line 26 defines one instance of our inner class **`ActionEventHandler`** (defined at lines 77–111) and assigns it to **`handler`**. This reference is passed to each of the four calls to **`addActionListener`** (lines 34, 40, 46 and 55) that register the event handlers for each GUI component that generates events in this example (**`hourField`**, **`minuteField`**, **`secondField`** and **`exitButton`**). Each call to **`addActionListener`** requires an object of type

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ActionListener to be passed as an argument. Actually, **handler** *is an* **ActionListener**. Line 77 (the first line of the inner class definition) indicates that inner class **ActionEventHandler** implements **ActionListener**. Thus, every object of type **ActionEventHandler** *is an* **ActionListener**. The requirement that **addActionListener** be passed an object of type **ActionListener** is satisfied! The *is a* relationship is used extensively in the GUI event-handling mechanism, as you will see over the next several chapters. The inner class is defined as **private** because it will be used only in this class definition. Inner classes can be **private**, **protected** or **public**.

An inner class object has a special relationship with the outer class object that creates it. The inner class object is allowed to access directly all the instance variables and methods of the outer class object. The **actionPerformed** method (line 77–105) of class **ActionEventHandler** does just that. Throughout the method, the instance variables **time**, **exitButton**, **hourField**, **minuteField** and **secondField** are used, as is method **displayTime**. Notice that none of these needs a "handle" to the outer class object. This is a free relationship created by the compiler between the outer class and its inner classes.

Software Engineering Observation 9.32

An inner class object is allowed to access directly all the variables and methods of the outer class object that defined it.

This application must be terminated by pressing the **Exit** button. Remember, an application that displays a window must be terminated with a call to **System.exit(0)**. Also note that a window in Java is 0 pixels wide, 0 pixels tall and not displayed by default. Lines 71–72 use methods **resize** and **setVisible** to size the window and display it on the screen. These methods are defined in class **java.awt.Component** originally and inherited into class **JFrame**.

An inner class can also be defined inside a method of a class. Such an inner class has access to its outer class's members. However, it has limited access to the local variables for the method in which it is defined.

Software Engineering Observation 9.33

An inner class defined in a method is allowed to access directly all the instance variables and methods of the outer class object that defined it and any ***final*** *local variables in the method.*

The application of Fig. 9.34 modifies class **TimeTestWindow** of Fig. 9.33 to use *anonymous inner classes* defined in methods. An anonymous inner class has no name, so one object of the anonymous inner class must be created at the point where the class is defined in the program. We demonstrate anonymous inner classes two ways in this example. First, we use separate anonymous inner classes that implement an interface (**ActionListener**) to create event handlers for each of the three **JTextField**s **hourField**, **minuteField** and **secondField**. We also demonstrate how to terminate an application when the user clicks the Close box on the window. The event handler is defined as an anonymous inner class that extends a class (**WindowAdapter**). The **Time** class used is identical to Fig. 9.32, so it is not included here. Also, the **Exit** button has been removed from this example.

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```
1  // Fig. 9.34: TimeTestWindow.java
2  // Demonstrating the Time class set and get methods
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class TimeTestWindow extends JFrame {
12    private Time time;
13    private JLabel hourLabel, minuteLabel, secondLabel;
14    private JTextField hourField, minuteField,
15       secondField, displayField;
16
17    // set up GUI
18    public TimeTestWindow()
19    {
20       super( "Inner Class Demonstration" );
21
22       // create Time object
23       time = new Time();
24
25       // create GUI
26       Container container = getContentPane();
27       container.setLayout( new FlowLayout() );
28
29       hourLabel = new JLabel( "Set Hour" );
30       hourField = new JTextField( 10 );
31
32       // register hourField event handler
33       hourField.addActionListener(
34
35          // anonymous inner class
36          new ActionListener() {
37
38             public void actionPerformed( ActionEvent event )
39             {
40                time.setHour(
41                   Integer.parseInt( event.getActionCommand() ) );
42                hourField.setText( "" );
43                displayTime();
44             }
45
46          }  // end anonymous inner class
47
48       ); // end call to addActionListener
49
50       container.add( hourLabel );
51       container.add( hourField );
52
```

Fig. 9.34 Demonstrating anonymous inner classes (part 1 of 4).

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```
53          minuteLabel = new JLabel( "Set minute" );
54          minuteField = new JTextField( 10 );
55
56          // register minuteField event handler
57          minuteField.addActionListener(
58
59             // anonymous inner class
60             new ActionListener() {
61
62                public void actionPerformed( ActionEvent event )
63                {
64                   time.setMinute(
65                      Integer.parseInt( event.getActionCommand() ) );
66                   minuteField.setText( "" );
67                   displayTime();
68                }
69
70             }  // end anonymous inner class
71
72          ); // end call to addActionListener
73
74          container.add( minuteLabel );
75          container.add( minuteField );
76
77          secondLabel = new JLabel( "Set Second" );
78          secondField = new JTextField( 10 );
79
80          secondField.addActionListener(
81
82             // anonymous inner class
83             new ActionListener() {
84
85                public void actionPerformed( ActionEvent event )
86                {
87                   time.setSecond(
88                      Integer.parseInt( event.getActionCommand() ) );
89                   secondField.setText( "" );
90                   displayTime();
91                }
92
93             }  // end anonymous inner class
94
95          ); // end call to addActionListener
96
97          container.add( secondLabel );
98          container.add( secondField );
99
100         displayField = new JTextField( 30 );
101         displayField.setEditable( false );
102         container.add( displayField );
103      }
104
```

Fig. 9.34 Demonstrating anonymous inner classes (part 2 of 4).

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```
105     // display time in displayField
106     public void displayTime()
107     {
108        displayField.setText( "The time is: " + time );
109     }
110
111     // create TimeTestWindow, register for its window events
112     // and display it to begin application's execution
113     public static void main( String args[] )
114     {
115        TimeTestWindow window = new TimeTestWindow();
116
117        // register listener for windowClosing event
118        window.addWindowListener(
119
120           // anonymous inner class for windowClosing event
121           new WindowAdapter() {
122
123              // terminate application when user closes window
124              public void windowClosing( WindowEvent event )
125              {
126                 System.exit( 0 );
127              }
128
129           }  // end anonymous inner class
130
131        ); // end call to addWindowListener
132
133        window.setSize( 400, 120 );
134        window.setVisible( true );
135     }
136
137  }  // end class TimeTestWindow
```

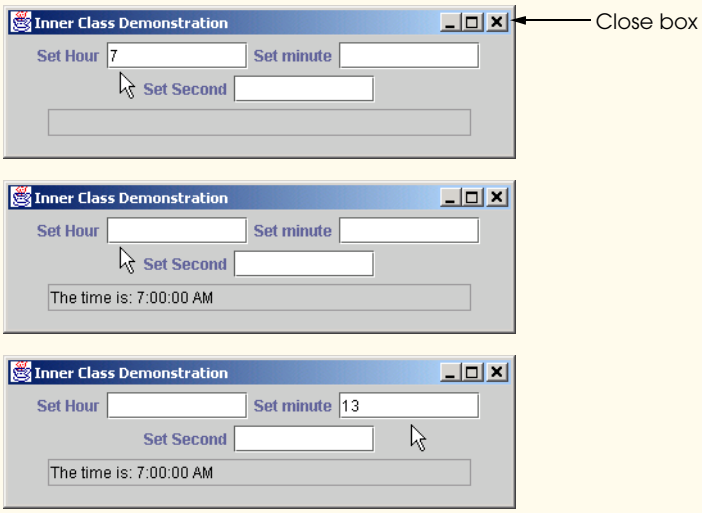

Fig. 9.34 Demonstrating anonymous inner classes (part 3 of 4).

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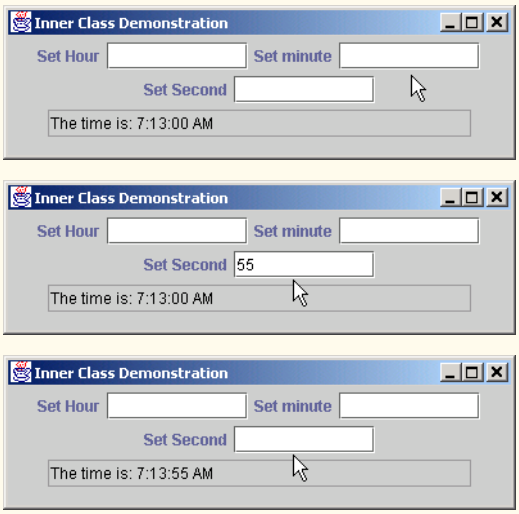

Fig. 9.34 Demonstrating anonymous inner classes (part 4 of 4).

Each of the three **JTextField**s that generate events in this program has a similar anonymous inner class to handle its events, so we discuss only the anonymous inner class for **hourField** here. Lines 33–48 are a call to **hourField**'s **addActionListener** method. The argument to this method must be an object that *is an* **ActionListener** (i.e., any object of a class that implements **ActionListener**). Lines 36–46 use special Java syntax to define an anonymous inner class and create one object of that class that is passed as the argument to **addActionListener**. Line 36 uses operator **new** to create an object. The syntax **ActionListener()** begins the definition of an anonymous inner class that implements interface **ActionListener**. This is similar to beginning a class definition with

```
public class MyHandler implements ActionListener {
```

The parentheses after **ActionListener** indicate a call to the default constructor of the anonymous inner class.

The opening left brace (**{**) at the end of line 36 and the closing right brace (**}**) at line 46 define the body of the class. Lines 38–44 define the **actionPerformed** method that is required in any class that implements **ActionListener**. Method **actionPerformed** is called when the user presses *Enter* while typing in **hourField**.

Software Engineering Observation 9.34

When an anonymous inner class implements an interface, the class must define every method in the interface.

Method **main** creates one instance of class **TimeTestWindow** (line 115), sizes the window (line 133) and displays the window (line 134).

Windows generate a variety of events that are discussed in Chapter 13. For this example we discuss the one event generated when the user clicks the window's close box—a *window closing event*. Lines 118–131 enable the user to terminate the application by

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clicking the window's close box (labeled in the first screen capture). Method ***addWindowListener*** registers a window event listener. The argument to **addWindowListener** must be a reference to an object that *is a* ***WindowListener*** (package **java.awt.event**) (i.e., any object of a class that implements **WindowListener**). However, there are seven different methods that must be defined in every class that implements **WindowListener** and we only need one in this example—***windowClosing***. For event handling interfaces with more than one method, Java provides a corresponding class (called an *adapter class*) that already implements all the methods in the interface for you. All you need to do is extend the adapter class and override the methods you require in your program.

Common Programming Error 9.10

Extending an adapter class and misspelling the name of the method you are overriding is a logic error.

Lines 121–129 use special Java syntax to define an anonymous inner class and create one object of that class that is passed as the argument to **addWindowListener**. Line 118 uses operator **new** to create an object. The syntax **WindowAdapter()** begins the definition of an anonymous inner class that extends class **WindowAdapter**. This is similar to beginning a class definition with

```
public class MyHandler extends WindowAdapter {
```

The parentheses after **WindowAdapter** indicate a call to the default constructor of the anonymous inner class. Class **WindowAdapter** implements interface **WindowListener**, so every **WindowAdapter** object *is a* **WindowListener**—the exact type required for the argument to **addWindowListener**.

The opening left brace (**{**) at the end of line 121 and the closing right brace (**}**) at line 129 define the body of the class. Lines 124–127 override the **windowClosing** method of **WindowAdapter** that is called when the user clicks the window's close box. In this example, **windowClosing** terminates the application.

In the last two examples, we have seen that inner classes can be used to create event handlers and that separate anonymous inner classes can be defined to handle events individually for each GUI component. In Chapter 12 and Chapter 13, we revisit this concept as we discuss the event handling mechanism in detail.

9.21 Notes on Inner Class Definitions

This section presents several notes of interest to programmers regarding the definition and use of inner classes.

1. Compiling a class that contains inner classes results in a separate **.class** file for every class. Inner classes with names have the file name *OuterClassName***$***InnerClassName***.class**. Anonymous inner classes have the file name *OuterClassName***$#.class**, where # starts at 1 and is incremented for each anonymous inner class encountered during compilation.
2. Inner classes with class names can be defined as **public**, **protected**, package access or **private** and are subject to the same usage restrictions as other members of a class.

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3. To access the outer class's **this** reference, use *OuterClassName*.**this**.
4. The outer class is responsible for creating objects of its inner classes. To create an object of another class's inner class, first create an object of the outer class and assign it to a reference (we will call it **ref**). Then use a statement of the following form to create an inner class object:

   OuterClassName.*InnerClassName* **innerRef = ref.new** *InnerClassName*();

5. An inner class can be declared **static**. A **static** inner class does not require an object of its outer class to be defined (whereas a non**static** inner class does). A **static** inner class does not have access to the outer class's non**static** members.

9.22 Type-Wrapper Classes for Primitive Types

Each of the primitive types has a *type-wrapper class*. These classes are called **Character**, **Byte**, **Short**, **Integer**, **Long**, **Float**, **Double** and **Boolean**. Each type-wrapper class enables you to manipulate primitive types as objects of class **Object**. Therefore, values of the primitive data types can be processed polymorphically if they are maintained as objects of the type-wrapper classes. Many of the classes we will develop or reuse manipulate and share **Object**s. These classes cannot polymorphically manipulate variables of primitive types, but they can polymorphically manipulate objects of the type-wrapper classes, because every class ultimately is derived from class **Object**.

Each of the numeric classes—**Byte**, **Short**, **Integer**, **Long**, **Float** and **Double**—inherits from class **Number**. Each of the type wrappers is declared **final**, so their methods are implicitly **final** and may not be overridden. Note that many of the methods that process the primitive data types are defined as **static** methods of the type-wrapper classes. If you need to manipulate a primitive value in your program, first refer to the documentation for the type-wrapper classes—the method you need might already be defined. We will use the type-wrapper classes polymorphically in our study of data structures in Chapters 22 and 23.

9.23 (Optional Case Study) Thinking About Objects: Incorporating Inheritance into the Elevator Simulation

We now examine our elevator simulator design to see whether it might benefit from inheritance. In previous chapters, we have been treating **ElevatorButton** and **FloorButton** as separate classes. These classes, however, have much in common—both have attribute **pressed** and behaviors **pressButton** and **resetButton**. To apply inheritance, we first look for commonality between these classes. We extract this commonality, place it into superclass **Button**, then derive subclasses **ElevatorButton** and **FloorButton** from **Button**.

Let us now examine the similarities between classes **ElevatorButton** and **FloorButton**. Figure 9.35 shows the attributes and operations of each class. Both classes have their attribute (**pressed**) and operations (**pressButton** and **resetButton**) in common.

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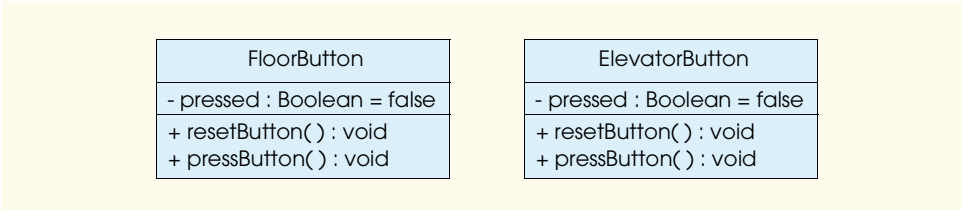

Fig. 9.35 Attributes and operations of classes **FloorButton** and **ElevatorButton**.

We must now examine whether these objects exhibit distinct behavior. If the **ElevatorButton** and **FloorButton** objects have the same behavior, then we cannot justify using two separate classes to instantiate these objects. However, if these objects have distinct behaviors, we can place the common attributes and operations in a superclass **Button**; then **ElevatorButton** and **FloorButton** inherit both the attributes and operations of **Button**.

We have been treating the **FloorButton** as if it behaves differently from the **ElevatorButton**—the **FloorButton** requests the **Elevator** to move to the **Floor** of the request, and the **ElevatorButton** signals the **Elevator** to move to the opposite **Floor**. Under closer scrutiny, we notice that both the **FloorButton** and the **ElevatorButton** signal the **Elevator** to move to a **Floor**, and the **Elevator** decides whether to move. The **Elevator** will sometimes move in response to a signal from the **FloorButton**, and the **Elevator** will always move in response to a signal from the **ElevatorButton**—however, neither the **FloorButton** nor the **ElevatorButton** decides for the **Elevator** that the **Elevator** must move to the other **Floor**. We conclude that both **FloorButton** and **ElevatorButton** have the same behavior—both signal the **Elevator** to move—so we *combine* (not inherit) classes into one **Button** class and discard class **FloorButton** and **ElevatorButton** from our case study.

We turn our attention to classes **ElevatorDoor** and **FloorDoor**. Figure 9.36 shows the attributes and operations of classes **ElevatorDoor** and **FloorDoor**—these two classes are structurally similar to each other as well, because both classes possess the attribute **open** and the two operations **openDoor** and **closeDoor**. In addition, both the **ElevatorDoor** and **FloorDoor** have the same behavior—they inform a **Person** that a door in the simulation has opened. The **Person** then decides either to enter or exit the **Elevator**, depending on which door opened. In other words, neither the **ElevatorDoor** nor the **FloorDoor** decides for the **Person** that the **Person** must enter or exit the **Elevator**. We combine both **ElevatorDoor** and **FloorDoor** into one **Door** class and eliminate classes **ElevatorDoor** and **FloorDoor** from our case study.[2]

2. As we continue to discuss inheritance throughout this section, we refer to the class diagram of Fig. 3.23 to determine similarities among objects. However, this diagram contains classes **FloorButton** and **ElevatorButton**, which we have eliminated recently from the case study. Therefore, during our discussion of inheritance, when we mention the **FloorButton**, we refer to that **Floor**'s **Button** object, and when we mention the **ElevatorButton**, we refer to the **Elevator**'s **Button** object.

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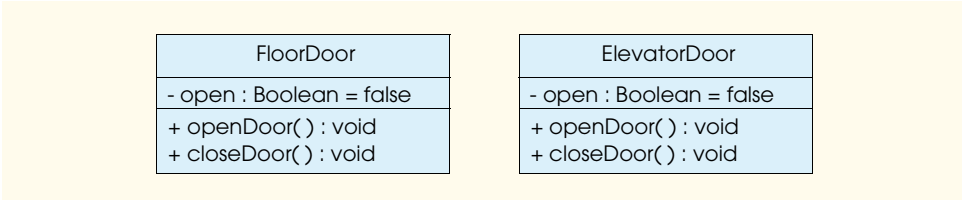

Fig. 9.36 Attributes and operations of classes **`FloorDoor`** and **`ElevatorDoor`**.

In Section 4.14, we encountered the problem of representing the location of the **`Person`**—on what **`Floor`** is the **`Person`** located when riding in the **`Elevator`**? Using inheritance, we may now model a solution. Both the **`Elevator`** and the two **`Floor`**s are locations at which the **`Person`** exists in the simulator. In other words, the **`Elevator`** and the **`Floor`**s are *types of* locations. Therefore, classes **`Elevator`** and **`Floor`** should inherit from an abstract superclass called **`Location`**. We declare class **`Location`** as abstract, because, for the purposes of our simulation, a location is too generic a term to define a real object. The UML requires that we place abstract class names (and abstract methods) in italics. Superclass **`Location`** contains the **`protected`** attribute **`locationName`**, which contains a **`String`** value of **`"firstFloor"`**, **`"secondFloor"`** or **`"elevator"`**. Therefore, only classes **`Elevator`** and **`Floor`** have access to **`locationName`**. In addition, we include the **`public`** method **`getLocationName`** to return the name of the location.

We search for more similarities between classes **`Floor`** and **`Elevator`**. First of all, according to the class diagram of Fig. 3.23, **`Elevator`** contains a reference to both a **`Button`** and a **`Door`**—the **`ElevatorButton`** (the **`Elevator`**'s **`Button`**) and the **`ElevatorDoor`** (the **`Elevator`**'s **`Door`**). Class **`Floor`**, through its association with class **`ElevatorShaft`** (class **`ElevatorShaft`** "connects" class **`Floor`**), also contains a reference to a **`Button`** and a **`Door`**—the **`FloorButton`** (that **`Floor`**'s **`Button`**) and the **`FloorDoor`** (that **`Floor`**'s **`Door`**). Therefore, in our simulation, the **`Location`** class, which is the superclass of classes **`Elevator`** and **`Floor`**, will contain **`public`** methods **`getButton`** and **`getDoor`**, which return a **`Button`** or **`Door`** reference, respectively. Class **`Floor`** overrides these methods to return the **`Button`** and **`Door`** references of that **`Floor`**, and class **`Elevator`** overrides these methods to return the **`Button`** and **`Door`** references of the **`Elevator`**. In other words, class **`Floor`** and **`Elevator`** exhibit distinct behavior from each other but share attribute **`locationName`** and methods **`getButton`** and **`getDoor`**—therefore, we may use inheritance for these classes.

The UML offers a relationship called a *generalization* to model inheritance. Figure 9.35 is the generalization diagram of superclass **`Location`** and subclasses **`Elevator`** and **`Floor`**. The empty-head arrows specify that classes **`Elevator`** and **`Floor`** inherit from class **`Location`**. Note that attribute **`locationName`** has an *access modifier* that we have not yet seen—the pound sign (**`#`**), indicating that **`locationName`** is a **`protected`** member, so **`Location`** subclasses may access this attribute. Note that classes **`Floor`** and **`Elevator`** contain additional attributes and methods that further distinguish these classes.

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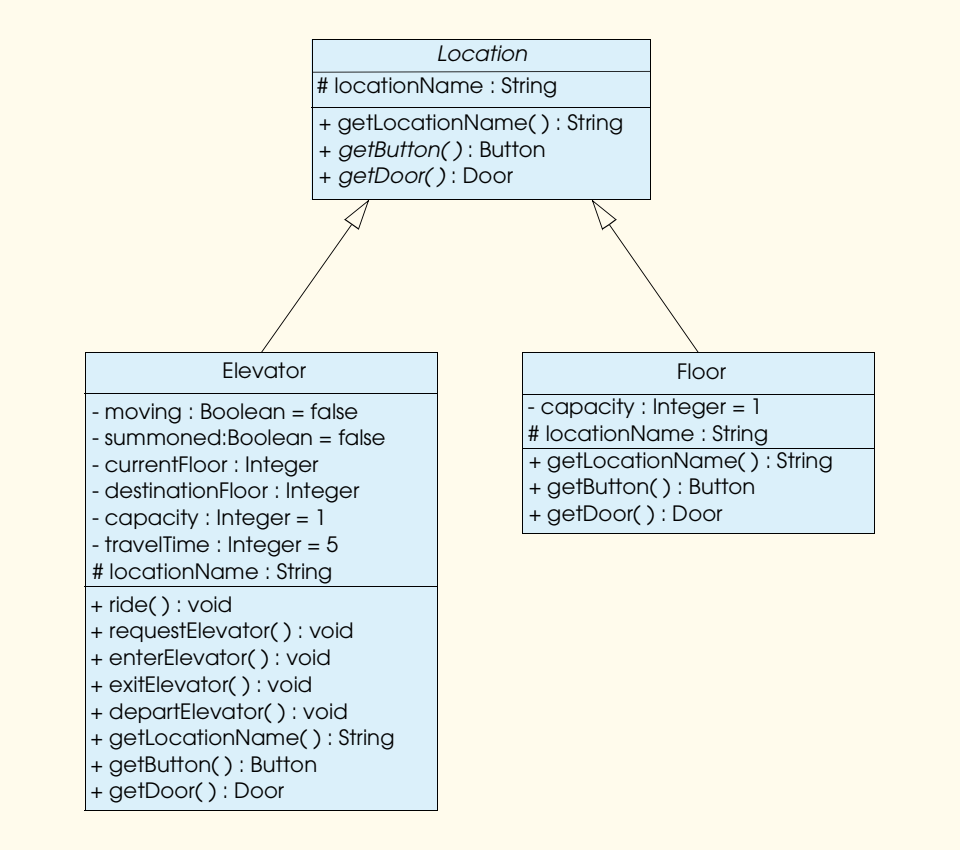

Fig. 9.37 Generalization diagram of superclass **`Location`** and subclasses **`Elevator`** and **`Floor`**.

Classes **`Floor`** and **`Elevator`** override methods **`getButton`** and **`getDoor`** from their superclass **`Location`**. In Fig. 9.37, these methods are italicized in class **`Location`**, indicating that they are *abstract methods*. However, the methods in the subclasses are not italicized—these methods became *concrete methods* by overriding the abstract methods. Class **`Person`** now contains a **`Location`** object representing whether the **`Person`** is on the first or second **`Floor`** or inside the **`Elevator`**. We remove the association between **`Person`** and **`Elevator`** and the association between **`Person`** and **`Floor`** from the class diagram, because the **`Location`** object acts as both the **`Elevator`** and **`Floor`** reference for the **`Person`**. A **`Person`** sets its **`Location`** object to reference the **`Elevator`** when that **`Person`** enters the **`Elevator`**. A **`Person`** sets its **`Location`** object to reference a **`Floor`** when the **`Person`** is on that **`Floor`**. Lastly, we assign class **`Elevator`** two **`Location`** objects to represent the **`Elevator`**'s reference to the current **`Floor`** and destination **`Floor`** (we originally used integers to describe these references). Figure 9.38 provides an updated class diagram of our model by incorporating inheritance and eliminating classes **`FloorButton`**, **`ElevatorButton`**, **`FloorDoor`** and **`ElevatorDoor`**.

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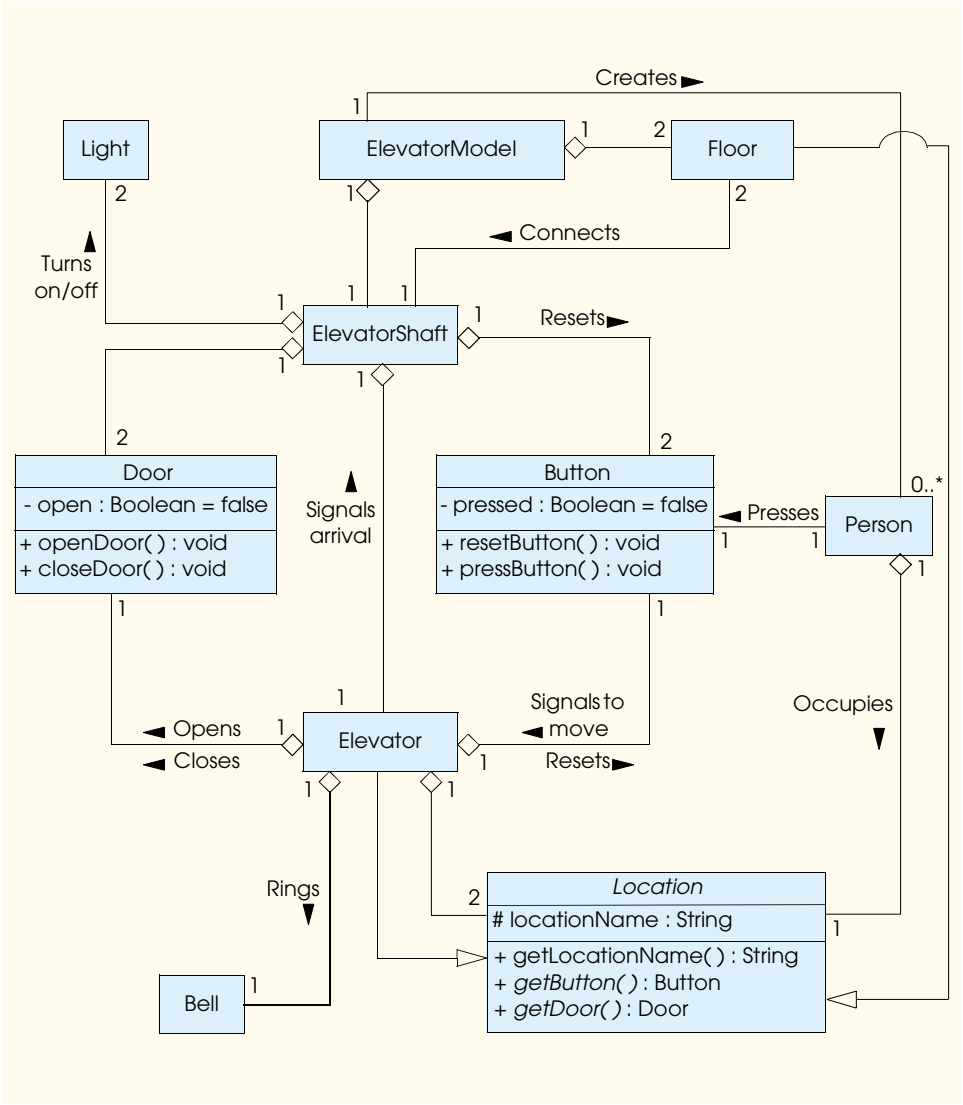

Fig. 9.38 Class diagram of our simulator (incorporating inheritance).

We have allowed a **`Person`**, occupying a **`Location`**, to interact with several of the objects in the simulator. For example, a **`Person`** can press a **`Button`** or be informed when a **`Door`** opens from that **`Person`**'s specific **`Location`**. In addition, because a **`Person`** may occupy only one **`Location`** at a time, that **`Person`** may interact with only the objects known to that **`Location`**—a **`Person`** will never perform an illegal action, such as pressing the first **`Floor`**'s **`Button`** while riding the **`Elevator`**.

We presented the class attributes and operations with access modifiers in Fig. 8.13. Now, we present a modified diagram incorporating inheritance in Fig. 9.39.

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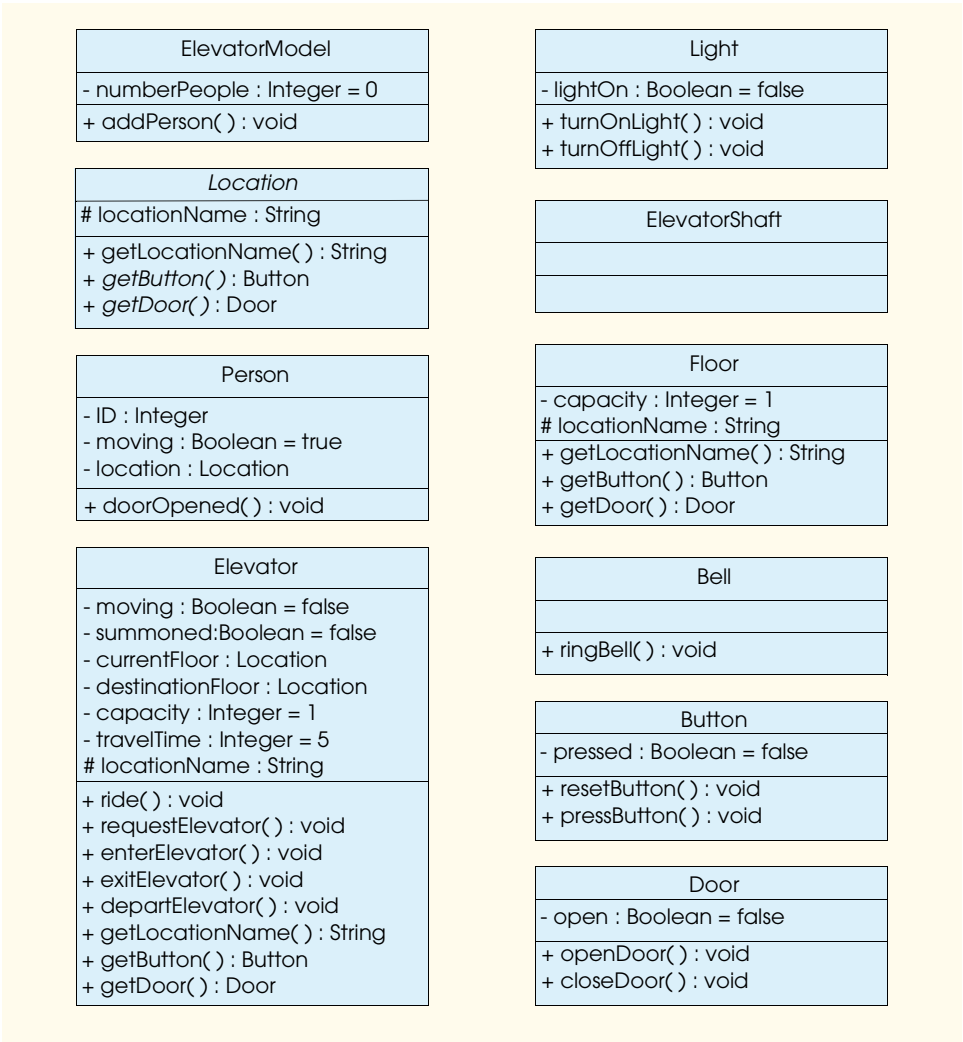

Fig. 9.39 Class diagram with attributes and operations (incorporating inheritance).

Class **`Elevator`** now contains two **`Location`** objects, called **`currentFloor`** and **`destinationFloor`**, replacing the integer values we used previously to describe the **`Floor`**s. Lastly, **`Person`** contains a **`Location`** object named **`location`**, which indicates whether **`Person`** is on a **`Floor`** or in the **`Elevator`**.

Implementation: Forward Engineering (Incorporating Inheritance)

"Thinking About Objects" Section 8.17 used the UML to express the Java class structure for our simulation. We continue our implementation while incorporating inheritance, using class **`Elevator`** as an example. For each class in the class diagram of Fig. 9.38,

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1. If a class **A** is a subclass of class **B**, then **A** extends **B** in the class declaration and calls the constructor of **B**. For example, class **Elevator** is a subclass of abstract superclass **Location**, so the class declaration should read

```
public class Elevator extends Location {

   public Elevator
   {
      super();
   }
...
```

2. If class **B** is an abstract class and class **A** is a subclass of class **B**, then class **A** must override the abstract methods of class **B** (if class **A** is to be a concrete class). For example, class **Location** contains abstract methods **getLocationName**, **getButton** and **getDoor**, so class **Elevator** must override these methods (note that **getButton** returns the **Elevator**'s **Button** object, and **getDoor** returns the **Elevator**'s **Door** object—**Elevator** contains associations with both objects, according to the class diagram of Fig. 9.38).

```
public class Elevator extends Location {

   // class attributes
   private boolean moving;
   private boolean summoned;
   private Location currentFloor;
   private Location destinationFloor;
   private int capacity = 1;
   private int travelTime = 5;

   // class objects
   private Button elevatorButton;
   private Door elevatorDoor;
   private Bell bell;

   // class constructor
   public Elevator()
   {
      super();
   }

   // class methods
   public void ride() {}
   public void requestElevator() {}
   public void enterElevator() {}
   public void exitElevator() {}
   public void departElevator() {}

   // method overriding getLocationName
   public String getLocationName()
   {
      return "elevator";
   }
```

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```
      // method overriding getButton
       public Button getButton() {}
      {
         return elevatorButton;
      }

      // method overriding getDoor
       public Door getDoor() {}
      {
         return elevatorDoor;
      }
   }
```

Using forward engineering provides a sound beginning for code implementation in any language. "Thinking About Objects" Section 11.10 returns to interactions and focuses on how objects generate and handle the messages passed in collaborations. In addition, we forward engineer more class diagrams to implement these interactions. Eventually, we present the Java code for our simulator in Appendix G, Appendix H and Appendix I.

9.24 (Optional) Discovering Design Patterns: Introducing Creational, Structural and Behavioral Design Patterns

Now that we have introduced object-oriented programming, we begin our deeper presentation of design patterns. In Section 1.17, we mentioned that the "gang of four" described 23 design patterns using three categories—creational, structural and behavioral. In this and the remaining "Discovering Design Patterns" sections, we discuss the design patterns of each type and their importance, and we mention how each pattern relates to the Java material in the book. For example, several Java Swing components that we introduce in Chapters 12 and 13 use the Composite design pattern, so we introduce the Composite design pattern in Section 13.18. Figure 9.40 identifies the 18 gang-of-four design patterns discussed in this book.

Figure 9.40 lists 18 of the most widely used patterns in the software-engineering industry. There are many popular patterns that have been documented since the gang-of-four book—these include the *concurrent design patterns*, which are especially helpful in the design of multithreaded systems. Section 15.13 discusses some of these patterns used in industry. Architectural patterns, as we discuss in Section 17.10, specify how subsystems interact with each other. Figure 9.41 specifies the concurrency patterns and architectural patterns that we discuss in this book.

Section	Creational design patterns	Structural design patterns	Behavioral design patterns
9.24	Singleton	Proxy	Memento State

Fig. 9.40 The 18 Gang-of-four design patterns discussed in *Java How to Program 4/e* (part 1 of 2).

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Section	Creational design patterns	Structural design patterns	Behavioral design patterns
13.18	Factory Method	Adapter Bridge Composite	Chain-of-Responsibility Command Observer Strategy Template Method
17.10	Abstract Factory	Decorator Facade	
21.12	Prototype		Iterator

Fig. 9.40 The 18 Gang-of-four design patterns discussed in *Java How to Program 4/e* (part 2 of 2).

Section	Concurrent design patterns	Architectural patterns
15.13	Single-Threaded Execution Guarded Suspension Balking Read/Write Lock Two-Phase Termination	
17.10		Model-View-Controller Layers

Fig. 9.41 Concurrent design patterns and architectural patterns discussed in *Java How to Program, 4/e*.

9.24.1 Creational Design Patterns

Creational design patterns address issues related to the creation of objects, such as preventing a system from creating more than one object of a class (the Singleton creational design pattern) or deferring until execution time the decision as to what types of objects are going to be created (the purpose of the other creational design patterns discussed here). For example, suppose we are designing a 3-D drawing program, in which the user can create several 3-D geometric objects, such as cylinders, spheres, cubes, tetrahedrons, etc. At compile time, the program does not know what shapes the user will choose to draw. Based on user input, this program should be able to determine the class from which to instantiate an object. If the user creates a cylinder in the GUI, our program should "know" to instantiate an object of class **`Cylinder`**. When the user decides what geometric object to draw, the program should determine the specific subclass from which to instantiate that object.

The gang-of-four book describes five creational patterns (four of which we discuss in this book):

- Abstract Factory (Section 17.10)
- Builder (not discussed)

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- Factory Method (Section 13.18)
- Prototype (Section 21.12)
- Singleton (Section 9.24)

Singleton

Occasionally, a system should contain exactly one object of a class—that is, once the program instantiates that object, the program should not be allowed to create additional objects of that class. For example, some systems connect to a database using only one object that manages database connections, which ensures that other objects cannot initialize unnecessary connections that would slow the system. The *Singleton design pattern* guarantees that a system instantiates a maximum of one object of a class.

Figure 9.42 demonstrates Java code using the Singleton design pattern. Line 5 declares class **`Singleton`** as **`final`**, so methods in this class cannot be overridden to handle multiple instantiations. Lines 11–14 declare a **`private`** constructor—only class **`Singleton`** can instantiate a **`Singleton`** object using this constructor. The **`static`** method **`getSingletonInstance`** (lines 17–24) allows the one-time instantiation of a **`static`** **`Singleton`** object (declared on line 8) by calling the **`private`** constructor. If the **`Singleton`** object has been created, line 23 merely returns a reference to the previously instantiated **`Singleton`** object.

Lines 10–11 of class **`SingletonExample`** (Fig. 9.43) declare two references to **`Singleton`** objects—**`firstSingleton`** and **`secondSingleton`**. Lines 14–15 call method **`getSingletonInstance`** and assign **`Singleton`** references to **`firstSingleton`** and **`secondSingleton`**, respectively. Line 18 tests if these objects reference the same **`Singleton`** object. Figure 9.44 shows that **`firstSingleton`** and **`secondSingleton`** share the same reference to the **`Singleton`** object, because each time method **`getSingletonInstance`** is called, it returns a reference to the same **`Singleton`** object.

```
1  // Singleton.java
2  // Demonstrates Singleton design pattern
3  package com.deitel.jhtp4.designpatterns;
4
5  public final class Singleton {
6
7     // Singleton object returned by method getSingletonInstance
8     private static Singleton singleton;
9
10    // constructor prevents instantiation from other objects
11    private Singleton()
12    {
13       System.err.println( "Singleton object created." );
14    }
15
16    // create Singleton and ensure only one Singleton instance
17    public static Singleton getSingletonInstance()
18    {
```

Fig. 9.42 Class **`Singleton`** ensures that only one object of its class is created (part 1 of 2).

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```
19         // instantiate Singleton if null
20         if ( singleton == null )
21            singleton = new Singleton();
22
23         return singleton;
24      }
25   }
```

Fig. 9.42 Class **Singleton** ensures that only one object of its class is created (part 2 of 2).

```
1  // SingletonExample.java
2  // Attempt to create two Singleton objects
3  package com.deitel.jhtp4.designpatterns;
4
5  public class SingletonExample {
6
7     // run SingletonExample
8     public static void main( String args[] )
9     {
10       Singleton firstSingleton;
11       Singleton secondSingleton;
12
13       // create Singleton objects
14       firstSingleton = Singleton.getSingletonInstance();
15       secondSingleton = Singleton.getSingletonInstance();
16
17       // the "two" Singletons should refer to same Singleton
18       if ( firstSingleton == secondSingleton )
19          System.out.println( "firstSingleton and " +
20             "secondSingleton refer to the same Singleton " +
21             "object" );
22    }
23 }
```

Fig. 9.43 Class **SingletonExample** attempts to create **Singleton** object more than once.

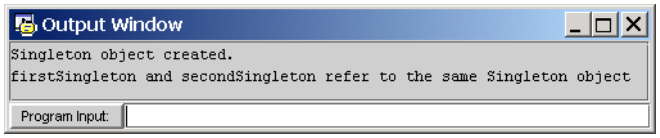

Fig. 9.44 Class **SingletonExample** output shows that the **Singleton** object may be created only once.

9.24.2 Structural Design Patterns

Structural design patterns describe common ways to organize classes and objects in a system. The gang-of-four book describes seven structural design patterns (six of which we discuss in this book):

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- Adapter (Section 13.18)
- Bridge (Section 13.18)
- Composite (Section 13.18)
- Decorator (Section 17.10)
- Facade (Section 17.10)
- Flyweight (not discussed)
- Proxy (Section 9.24)

Proxy

An applet should always display something while images load. Whether that "something" is a smaller image or a string of text informing the user that the images are loading, the *Proxy design pattern* can be applied to achieve this effect. This pattern allows one object to act as a replacement for another. Consider loading several large images (several megabytes) in a Java applet. Ideally, we would like to see these images instantaneously—however, loading large images into memory can take time to complete (especially on a slow processor). The Proxy design pattern allows the system to use one object—called a *proxy object*—in place of another. In our example, the proxy object could be a gauge that informs the user of what percentage of a large image has been loaded. When this image finishes loading, the proxy object is no longer needed—the applet can then display an image instead of the proxy.

9.24.3 Behavioral Design Patterns

There are many different examples of *behavioral design patterns*, which provide proven strategies to model how objects collaborate with one another in a system and offer special behaviors appropriate for a wide variety of applications. Let us consider the Observer behavioral design pattern—a classic example of a design pattern illustrating collaborations between objects. For example, GUI components collaborate with their listeners to respond to user interactions. GUI components use this pattern to process user interface events. A listener observes state changes in a particular GUI component by registering to handle that GUI component's events. When the user interacts with that GUI component, the component notifies its listeners (also known as its observers) that the GUI component's state has changed (e.g., a button has been pressed).

Another pattern we consider is the Memento behavioral design pattern—an example of offering special behavior for a wide variety of applications. The Memento pattern enables a system to save an object's state, so that state can be restored at a later time. For example, many applications provide an "undo" capability that allows users to revert to previous versions of their work.

The gang-of-four book describes 11 behavioral design patterns (eight of which we discuss in this book):

- Chain-of-Responsibility (Section 13.18)
- Command (Section 13.18)
- Interpreter (not discussed)
- Iterator (Section 21.12)

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- Mediator (not discussed)
- Memento (Section 9.24)
- Observer (Section 13.18)
- State (Section 9.24)
- Strategy (Section 13.18)
- Template Method (Section 13.18)
- Visitor (not discussed)

Memento

Consider a painting program. This type of program allows a user to create graphics. Occasionally the user may position a graphic improperly in the drawing area. Painting programs offer an "undo" feature that allows the user to unwind such an error. Specifically, the program restores the drawing area's state to that before the user placed the graphic. More sophisticated painting programs offer a *history*, which stores several states in a list, so the user can restore the program to any state in the history.The *Memento design pattern* allows an object to save its state, so that—if necessary—the object can be restored to its former state.

The Memento design pattern requires three types of objects. The *originator object* occupies some *state*—the set of attribute values at a specific time in program execution. In our painting-program example, the drawing area acts as the originator, because it contains attribute information describing its state—when the program first executes, the area contains no elements. The *memento object* stores a copy of all attributes associated with the originator's state—i.e., the memento saves the drawing area's state. The memento is stored as the first item in the history list, which acts as the *caretaker object*—the object that contains references to all memento objects associated with the originator.

Now, suppose the user draws a circle in the drawing area. The area contains different information describing its state—a circle object centered at specified *x*-*y* coordinates. The drawing area then uses another memento to store this information. This memento is stored as the second item in the history list. The history list displays all mementos on screen, so the user can select which state to restore. Suppose the user wishes to remove the circle—if the user selects the first memento from the list, the drawing area uses the first memento to restore itself to a blank area.

State

In certain designs, we must convey an object's state information or represent the various states that an object can occupy. Our optional elevator simulation case study in the "Thinking About Objects" sections uses the *State design pattern*. Our simulation includes an elevator that moves between floors in a two-story building. A person walks across a floor and rides the elevator to the other floor. Originally, we used an integer value to represent on which floor the person is walking. However, we encountered a problem when we tried to answer the question "on what floor is the person when riding the elevator?" Actually, the person is located on neither floor—rather the person is located inside the elevator. We also realized that the elevator and the floors are locations that the person can occupy in our simulation. We created an abstract superclass called **`Location`** to represent a "location." Subclasses **`Elevator`** and **`Floor`** inherit from superclass **`Location`**. Class **`Person`** contains a reference to a **`Location`** object, which represents the current location—eleva-

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tor, first floor or second floor—of that person. Because a superclass reference can hold a subclass reference, the person's **Location** attribute references the appropriate **Floor** object when that person is on a floor and references the **Elevator** object when that person is inside the elevator.

The elevator and floors contain buttons. (The elevator's button signals the elevator to move to the other floor, and the floors' buttons summon the elevator to the floor of the request.) Because all locations in our simulation contain buttons, class **Location** provides abstract method **getButton**. Class **Elevator** implements method **getButton** to return a reference to the **Button** object inside the elevator, and class **Floor** implements method **getButton** to return a reference to the **Button** object on the floor. Using its **Location** reference, the person is able to press the correct button—i.e., the person will not press a floor's button when inside the elevator and will not press the elevator's button when on a floor.

The State design pattern uses an abstract superclass—called the *State class*—which contains methods that describe behaviors for states that an object (called the *context object*) can occupy. In our elevator simulation, the State class is superclass **Location**, and the context object is the object of class **Person**. Note that class **Location** does not describe all states of class **Person** (e.g., whether that person is walking or waiting for the elevator)—class **Location** describes only the location the **Person** and contains method **getButton** so the **Person** can access the **Button** object at various locations.

A *State subclass*, which extends the State class, represents an individual state that the context can occupy. The State subclasses in our simulation are classes **Elevator** and **Floor**. Each State subclass contains methods that implement the State class' abstract methods. For example, both classes **Elevator** and **Floor** implement method **getButton**.

The context contains exactly one reference to an object of the State class—this reference is called the *state object*. In the simulation, the state object is the object of class **Location**. When the context changes state, the state object references the State subclass object associated with that new state. For example, when the person walks from the floor into the elevator, the **Person** object's **Location** is changed from referencing one of the **Floor** objects to referencing the **Elevator** object. When the person walks onto the floor from the elevator, the **Person** object's **Location** references the appropriate **Floor** object.

9.24.4 Conclusion

In "Discovering Design Patterns" Section 9.24, we listed the three types of design patterns introduced in the gang-of-four book, we identified 18 of these design patterns that we discuss in this book and we discussed specific design patterns, including Singleton, Proxy, Memento and State. In "Discovering Design Patterns" Section 13.18, we introduce some design patterns associated with AWT and Swing GUI components. After reading this section, you should understand better how Java GUI components take advantage of design patterns.

9.24.5 Internet and World-Wide-Web Resources

The following URLs provide further information on the nature, importance and applications of design patterns.

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Design Patterns

www.hillside.net/patterns
This page displays links to information on design patterns and languages.

www.hillside.net/patterns/books/
This site lists books on design patterns.

www.netobjectives.com/design.htm
This site introduces the importance of design patterns.

umbc7.umbc.edu/~tarr/dp/dp.html
This site links to design patterns Web sites, tutorials and papers.

www.links2go.com/topic/Design_Patterns
This site links to sites and information on design patterns.

www.c2.com/ppr/
This site discusses recent advances in design patterns and ideas for future projects.

Design Patterns in Java

www.research.umbc.edu/~tarr/cs491/fall00/cs491.html
This site is for a Java design patterns course at the University of Maryland and contains numerous examples of how to apply design patterns in Java.

www.enteract.com/~bradapp/javapats.html
This site discusses Java design patterns and presents design patterns in distributed computing.

www.meurrens.org/ip-Links/java/designPatterns/
This site displays numerous links to resources and information on Java design patterns.

Design Patterns in C++ & Visual Basic

journal.iftech.com/articles/9904_shankel_patterns/
This site provides insight to design patterns (the Iterator design pattern, in particular) in C++.

mspress.microsoft.com/prod/books/sampchap/2322.htm
This site overviews the book, *Microsoft Visual Basic Design Patterns* (Microsoft Press: 2000).

Architectural Patterns

compsci.about.com/science/compsci/library/weekly/aa030600a.htm
This site provides an overview the Model-View-Controller architecture.

www.javaworld.com/javaworld/jw-04-1998/jw-04-howto.html
This site contains an article discussing how Swing components use Model-View-Controller architecture.

www.ootips.org/mvc-pattern.html
This site provides information and tips on using MVC.

www.ftech.co.uk/~honeyg/articles/pda.htm
This site contains an article on the importance of architectural patterns in software.

www.tml.hut.fi/Opinnot/Tik-109.450/1998/niska/sld001.htm
This site provides information on architectural patterns, design pattern, and idioms (patterns targeting a specific language).

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SUMMARY

- One of the keys to the power of object-oriented programming is achieving software reusability through inheritance.
- Through inheritance, a new class inherits the instance variables and methods of a previously defined superclass. In this case, the new class is referred to as a subclass.
- With single inheritance, a class is derived from one superclass. With multiple inheritance, a subclass inherits from multiple superclasses. Java does not support multiple inheritance, but Java does provide the notion of interfaces, which offer many of the benefits of multiple inheritance.
- A subclass normally adds instance variables and methods of its own, so a subclass generally is larger than its superclass. A subclass represents a smaller set of more specific objects than its superclass.
- A subclass cannot access the **`private`** members of its superclass. A subclass can, however, access the **`public`**, **`protected`** and package access members of its superclass. The subclass must be in the superclass's package to use superclass members with package access.
- A subclass constructor always calls the constructor for its superclass first (either explicitly or implicitly) to create and initialize the subclass members inherited from the superclass.
- Inheritance enables software reusability, which saves time in development and encourages the use of previously proven and debugged high-quality software.
- An object of a subclass can be treated as an object of its corresponding superclass, but the reverse is not true.
- A superclass exists in a hierarchical relationship with its subclasses.
- When a class is used with the mechanism of inheritance, it becomes either a superclass that supplies attributes and behaviors to other classes or a subclass that inherits those attributes and behaviors.
- An inheritance hierarchy can be arbitrarily deep within the physical limitations of a particular system, but most inheritance hierarchies have only a few levels.
- Hierarchies are useful for understanding and managing complexity. With software becoming increasingly complex, Java provides mechanisms for supporting hierarchical structures through inheritance and polymorphism.
- Modifier **`protected`** serves as an intermediate level of protection between **`public`** access and **`private`** access. Superclass **`protected`** members may be accessed by methods of the superclass, by methods of subclasses and by methods of classes in the same package.
- A superclass may be either a direct superclass or an indirect superclass. A direct superclass is the class that a subclass explicitly **`extends`**. An indirect superclass is inherited from several levels up the class hierarchy tree.
- When a superclass member is inappropriate for a subclass, the programmer must override that member in the subclass.
- In a "has a" relationship, a class object has a reference to an object of another class as a member. In an "is a" relationship, an object of a subclass type may also be treated as an object of the superclass type. "Is a" is inheritance. "Has a" is composition.
- A reference to a subclass object may be converted implicitly to a reference for a superclass object.
- It is possible to convert a superclass reference to a subclass reference by using an explicit cast. If the target object is not a subclass object, a **`ClassCastException`** is thrown.
- A superclass specifies commonality. All classes derived from a superclass inherit the capabilities of that superclass. In the object-oriented design process, the designer looks for commonality among classes and factors it out to form superclasses. Then, subclasses are customized beyond the capabilities inherited from the superclass.

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- Reading a set of subclass declarations can be confusing, because inherited superclass members are not listed in the subclass declarations, but these members are indeed present in the subclasses.
- With polymorphism, it becomes possible to design and implement systems that are more extensible. Programs can be written to process objects of types that may not exist when the program is under development.
- Polymorphic programming can eliminate the need for **`switch`** logic, thus avoiding the kinds of errors associated with **`switch`** logic.
- An abstract method is declared by preceding the method's definition with the keyword **`abstract`** in the superclass.
- There are many situations in which it is useful to define classes for which the programmer never intends to instantiate any objects. Such classes are called **`abstract`** classes. Because these are used only as superclasses, typically they are called **`abstract`** superclasses. A program cannot instantiate objects of an **`abstract`** class.
- Classes from which a program can instantiate objects are called concrete classes.
- A class is made abstract by declaring it with the keyword **`abstract`**.
- If a subclass is derived from a superclass with an **`abstract`** method without supplying a definition for that **`abstract`** method in the subclass, that method remains **`abstract`** in the subclass. Consequently, the subclass is also an **`abstract`** class.
- When a request is made through a superclass reference to use a method, Java chooses the correct overridden method in the subclass associated with the object.
- Through the use of polymorphism, one method call can cause different actions to occur, depending on the type of the object receiving the call.
- Although we cannot instantiate objects of **`abstract`** superclasses, we can declare references to **`abstract`** superclasses. Such references can then be used to enable polymorphic manipulations of subclass objects when such objects are instantiated from concrete classes.
- New classes are regularly added to systems. New classes are accommodated by dynamic method binding (also called late binding). The type of an object need not be known at compile time for a method call to be compiled. At execution time, the appropriate method of the receiving object is selected.
- With dynamic method binding, at execution time the call to a method is routed to the method version appropriate for the class of the object receiving the call.
- When a superclass provides a method, subclasses can override the method, but they do not have to override it. Thus a subclass can use a superclass's version of a method.
- An interface definition begins with the keyword **`interface`** and contains a set of **`public abstract`** methods. Interfaces may also contain **`public static final`** data.
- To use an interface, a class must specify that it **`implements`** the interface and that class must define every method in the interface with the number of arguments and the return type specified in the interface definition.
- An interface is typically used in place of an abstract class when there is no default implementation to inherit.
- When a class implements an interface, the same "is a" relationship provided by inheritance applies.
- To implement more than one interface, simply provide a comma-separated list of interface names after keyword **`implements`** in the class definition.
- Inner classes are defined inside the scope of other classes.

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- An inner class can also be defined inside a method of a class. Such an inner class has access to its outer class's members and to the **`final`** local variables for the method in which it is defined.
- Inner class definitions are used mainly in event handling.
- Class **`JFrame`** provides the basic attributes and behaviors of a window—a title bar and buttons to minimize, maximize and close the window.
- An inner class object has access to all the variables and methods of the outer class object.
- Because an anonymous inner class has no name, one object of the anonymous inner class must be created at the point where the class is defined in the program.
- An anonymous inner class can implement an interface or extend a class.
- The event generated when the user clicks the window's close box is a window closing event.
- Method **`addWindowListener`** registers a window event listener. The argument to **`addWindowListener`** must be a reference to an object that is a **`WindowListener`** (package **`java.awt.event`**).
- For event handling interfaces with more than one method, Java provides a corresponding class (called an adapter class) that already implements all the methods in the interface for you. Class **`WindowAdapter`** implements interface **`WindowListener`**, so every **`WindowAdapter`** object *is a* **`WindowListener`**.
- Compiling a class that contains inner classes results in a separate **`.class`** file for every class.
- Inner classes with class names can be defined as **`public`**, **`protected`**, package access or **`private`** and are subject to the same usage restrictions as other members of a class.
- To access the outer class's **`this`** reference, use *OuterClassName*`.this`.
- The outer class is responsible for creating objects of its non**`static`** inner classes.
- An inner class can be declared **`static`**.

TERMINOLOGY

`abstract` class
`abstract` method
`abstract` superclass
abstraction
anonymous inner class
base class
`Boolean` class
`Character` class
class hierarchy
client of a class
composition
direct superclass
`Double` class
dynamic method binding
extends
extensibility
`final` class
`final` instance variable
`final` method
garbage collection
"has a" relationship
hierarchical relationship
implementation inheritance
implicit reference conversion
indirect superclass
infinite recursion error
inheritance
inheritance hierarchy
inner class
`Integer` class
interface
interface inheritance
"is a" relationship
`JFrame` class
late binding
`Long` class
member access control
member object
method overriding
multiple inheritance
`Number` class
`Object` class

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object-oriented programming (OOP)
override a method
override an **abstract** method
overriding vs. overloading
polymorphism
protected member of a class
reference to an **abstract** class
setSize method
setVisible method
single inheritance
software reusability
standardized software components
subclass
subclass constructor
subclass reference
super
superclass
superclass constructor
superclass reference
switch logic
this
type-wrapper class
"uses a" relationship
WindowAdapter class
windowClosing method
WindowEvent class
WindowListener interface

SELF-REVIEW EXERCISES

9.1 Fill in the blanks in each of the following statements:

a) If the class **Alpha** inherits from the class **Beta**, class **Alpha** is called the _____ class and class **Beta** is called the _____ class.
b) Inheritance enables _____, which saves time in development and encourages using previously proven and high-quality software components.
c) An object of a _____ class can be treated as an object of its corresponding _____ class.
d) The four member access specifiers are _____, _____, _____ and _____.
e) A "has a" relationship between classes represents _____ and an "is a" relationship between classes represents _____.
f) Using polymorphism helps eliminate _____ logic.
g) If a class contains one or more **abstract** methods, it is an _____class.
h) A method call resolved at run-time is referred to as _____ binding.
i) A subclass may call any non**private** superclass method by prepending _____ to the method call.

9.2 State whether each of the following statements is *true* or *false*. If *false*, explain why.

a) A superclass typically represents a larger number of objects than its subclass represents (true/false).
b) A subclass typically encapsulates less functionality than does its superclass. (true/false).

ANSWERS TO SELF-REVIEW EXERCISES

9.1 a) sub, super. b) software reusability. c) sub, super. d) **public**, **protected**, **private** and package access. e) composition, inheritance. f) **switch**. g) **abstract**. h) dynamic. i) **super**.

9.2 a) True.
b) False. A subclass includes all the functionality of its superclass.

EXERCISES

9.3 Consider the class **Bicycle**. Given your knowledge of some common components of bicycles, show a class hierarchy in which the class **Bicycle** inherits from other classes, which, in turn, inherit from yet other classes. Discuss the instantiation of various objects of class **Bicycle**. Discuss inheritance from class **Bicycle** for other closely related subclasses.

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9.4 Define each of the following terms: single inheritance, multiple inheritance, interface, superclass and subclass.

9.5 Discuss why casting a superclass reference to a subclass reference is potentially dangerous.

9.6 Distinguish between single inheritance and multiple inheritance. What feature of Java helps realize the benefits of multiple inheritance?

9.7 (*True/False*) A subclass is generally smaller than its superclass.

9.8 (*True/False*) A subclass object is also an object of that subclass's superclass.

9.9 Some programmers prefer not to use **`protected`** access because it breaks information hiding in the superclass. Discuss the relative merits of using **`protected`** access vs. **`private`** access in superclasses.

9.10 Many programs written with inheritance could be solved with composition instead, and vice versa. Discuss the relative merits of these approaches in the context of the **`Point`**, **`Circle`**, **`Cylinder`** class hierarchy in this chapter. Rewrite the program of Fig. 9.22–Fig. 9.26 (and the supporting classes) to use composition rather than inheritance. After you do this, reassess the relative merits of the two approaches both for the **`Point`**, **`Circle`**, **`Cylinder`** problem and for object-oriented programs in general.

9.11 Rewrite the **`Point`**, **`Circle`**, **`Cylinder`** program of Fig. 9.22–Fig. 9.26 as a **`Point`**, **`Square`**, **`Cube`** program. Do this two ways—once with inheritance and once with composition.

9.12 In the chapter, we stated, "When a superclass method is inappropriate for a subclass, that method can be overridden in the subclass with an appropriate implementation." If this is done, does the subclass-is-a-superclass-object relationship still hold? Explain your answer.

9.13 Study the inheritance hierarchy of Fig. 9.2. For each class, indicate some common attributes and behaviors consistent with the hierarchy. Add some other classes (e.g., **`UndergraduateStudent`**, **`GraduateStudent`**, **`Freshman`**, **`Sophomore`**, **`Junior`**, **`Senior`**), to enrich the hierarchy.

9.14 Write an inheritance hierarchy for classes **`Quadrilateral`**, **`Trapezoid`**, **`Parallelogram`**, **`Rectangle`** and **`Square`**. Use **`Quadrilateral`** as the superclass of the hierarchy. Make the hierarchy as deep (i.e., as many levels) as possible. The **`private`** data of **`Quadrilateral`** should include the *(x, y)* coordinate pairs for the four endpoints of the **`Quadrilateral`**. Write a driver program that instantiates and displays objects of each of these classes. [In Chapter 11, "Graphics and Java2D," you will learn how to use Java's drawing capabilities.]

9.15 Write down all the shapes you can think of—both two-dimensional and three-dimensional—and form those shapes into a shape hierarchy. Your hierarchy should have superclass **`Shape`**, from which class **`TwoDimensionalShape`** and class **`ThreeDimensionalShape`** are derived. Once you have developed the hierarchy, define each of the classes in the hierarchy. We will use this hierarchy in the exercises to process all shapes as objects of superclass **`Shape`**.

9.16 How is it that polymorphism enables you to program "in the general" rather than "in the specific"? Discuss the key advantages of programming "in the general."

9.17 Discuss the problems of programming with **`switch`** logic. Explain why polymorphism is an effective alternative to using **`switch`** logic.

9.18 Distinguish between inheriting interface and inheriting implementation. How do inheritance hierarchies designed for inheriting interface differ from those designed for inheriting implementation?

9.19 Distinguish between non**`abstract`** methods and **`abstract`** methods.

9.20 (*True/False*) All methods in an **`abstract`** superclass must be declared **`abstract`**.

9.21 Suggest one or more levels of **`abstract`** superclasses for the **`Shape`** hierarchy discussed in the beginning of this chapter (the first level is **`Shape`** and the second level consists of the classes **`TwoDimensionalShape`** and **`ThreeDimensionalShape`**).

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9.22 How does polymorphism promote extensibility?

9.23 You have been asked to develop a flight simulator that will have elaborate graphical outputs. Explain why polymorphic programming would be especially effective for a problem of this nature.

9.24 Develop a basic graphics package. Use the **Shape** class inheritance hierarchy from Figure 9.3. Limit yourself to two-dimensional shapes such as squares, rectangles, triangles and circles. Interact with the user. Let the user specify the position, size, shape and fill colors to be used in drawing each shape. The user can specify many items of the same shape. As you create each shape, place a **Shape** reference to each new **Shape** object into an array. Each class has its own **draw** method. Write a polymorphic screen manager that walks through the array sending **draw** messages to each object in the array to form a screen image. Redraw the screen image each time the user specifies an additional shape. Investigate the methods of class **Graphics** to help draw each shape.

9.25 Modify the payroll system of Fig. 9.16–Fig. 9.21 to add **private** instance variables **birthDate** (use class **Date** from Figure 8.13) and **departmentCode** (an **int**) to class **Employee**. Assume this payroll is processed once per month. Then, as your program calculates the payroll for each **Employee** (polymorphically), add a $100.00 bonus to the person's payroll amount if this is the month in which the **Employee**'s birthday occurs.

9.26 In Exercise 9.15, you developed a **Shape** class hierarchy and defined the classes in the hierarchy. Modify the hierarchy so that class **Shape** is an **abstract** superclass containing the interface to the hierarchy. Derive **TwoDimensionalShape** and **ThreeDimensionalShape** from class **Shape**—these classes should also be **abstract**. Use an **abstract print** method to output the type and dimensions of each class. Also include **area** and **volume** methods so these calculations can be performed for objects of each concrete class in the hierarchy. Write a driver program that tests the **Shape** class hierarchy.

9.27 Rewrite your solution to Exercise 9.26 to use a **Shape** interface instead of an abstract **Shape** class.

9.28 *(Drawing Application)* Modify the drawing program of Exercise 8.19 to create a drawing application that draws random lines, rectangles and ovals. [*Note:* Like an applet, a **JFrame** has a **paint** method that you can override to draw on the background of the **JFrame**.]

For this exercise, modify the **MyLine**, **MyOval** and **MyRect** classes of Exercise 8.19 to create the class hierarchy in Fig. 9.45. The classes of the **MyShape** hierarchy should be "smart" shape classes where objects of these classes know how to draw themselves (if provided with a **Graphics** object that tells them where to draw). The only **switch** or **if/else** logic in this program should be to determine the type of shape object to create (use random numbers to pick the shape type and the coordinates of each shape). Once an object from this hierarchy is created, it will be manipulated for the rest of its lifetime as a superclass **MyShape** reference.

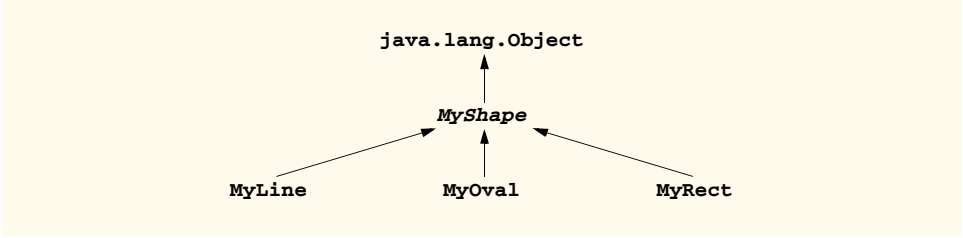

Fig. 9.45 The **MyShape** hierarchy.

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Class **MyShape** in Fig. 9.45 *must* be **abstract**. The only data representing the coordinates of the shapes in the hierarchy should be defined in class **MyShape**. Lines, rectangles and ovals can all be drawn if you know two points in space. Lines require *x1*, *y1*, *x2* and *y2* coordinates. The **drawLine** method of the **Graphics** class will connect the two points supplied with a line. If you have the same four coordinate values (*x1*, *y1*, *x2* and *y2*) for ovals and rectangles, you can calculate the four arguments needed to draw them. Each requires an upper-left *x*-coordinate value (minimum of the two *x*-coordinate values), an upper-left *y*-coordinate value (minimum of the two *y* coordinate values), a *width* (difference between the two *x*-coordinate values; must be nonnegative) and a *height* (difference between the two *y*-coordinate values; must be nonnegative). [*Note*: In Chapter 12, each *x,y* pair will be captured by using mouse events from mouse interactions between the user and the program's background. These coordinates will be stored in an appropriate shape object as selected by the user. As you begin the exercise, you will use random coordinate values as arguments to the constructor.]

In addition to the data for the hierarchy, class **MyShape** should define at least the following methods:

a) A constructor with no arguments that sets the coordinates to 0.
b) A constructor with arguments that sets the coordinates to the supplied values.
c) Set methods for each individual piece of data that allow the programmer to independently set any piece of data for a shape in the hierarchy (e.g., if you have an instance variable **x1**, you should have a method **setX1**).
d) Get methods for each individual piece of data that allow the programmer to independently retrieve any piece of data for a shape in the hierarchy (e.g., if you have an instance variable **x1**, you should have a method **getX1**).
e) The **abstract** method

```
public abstract void draw( Graphics g );
```

This method will be called from the program's **paint** method to draw a shape onto the screen.

The preceding methods are required. If you would like to provide more methods for flexibility, please do so. However, be sure that any method you define in this class is a method that would be used by *all* shapes in the hierarchy.

All data *must* be **private** to class **MyShape** in this exercise (this forces you to use proper encapsulation of the data and provide proper *set/get* methods to manipulate the data). You are not allowed to define new data that can be derived from existing information. As explained previously, the upper-left *x*, upper-left *y*, *width* and *height* needed to draw an oval or rectangle can be calculated if you already know two points in space. All subclasses of **MyShape** should provide two constructors that mimic those provided by class **MyShape**.

Objects of the **MyOval** and **MyRect** classes should not calculate their upper-left *x*-coordinate, upper-left *y*-coordinate, *width* and *height* until they are about to draw. Never modify the *x1*, *y1*, *x2* and *y2* coordinates of a **MyOval** or **MyRect** object to prepare to draw them. Instead, use the temporary results of the calculations described above. This will help us enhance the program in Chapter 12 by allowing the user to select each shape's coordinates with the mouse.

There should be no **MyLine**, **MyOval** or **MyRect** references in the program—only **MyShape** references that refer to **MyLine**, **MyOval** and **MyRect** objects are allowed. The program should keep an array of **MyShape** references containing all shapes. The program's **paint** method should walk through the array of **MyShape** references and draw every shape (i.e., call every shape's **draw** method).

Begin by defining class **MyShape**, class **MyLine** and an application to test your classes. The application should have a **MyShape** instance variable that can refer to one **MyLine** object (created

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in the application's constructor). The **paint** method (for your subclass of **JFrame**) should draw the shape with a statement like

```
currentShape.draw( g );
```

where **currentShape** is the **MyShape** reference and **g** is the **Graphics** object that the shape will use to draw itself on the background of the window.

9.29 Next, change the single **MyShape** reference into an array of **MyShape** references and hard code several **MyLine** objects into the program for drawing. The application's **paint** method should walk through the array of shapes and draw every shape.

After the preceding part is working, you should define the **MyOval** and **MyRect** classes and add objects of these classes into the existing array. For now, all the shape objects should be created in the constructor for your subclass of **JFrame**. In Chapter 12, we will create the objects when the user chooses a shape and begins drawing it with the mouse.

In Exercise 9.28, you defined a **MyShape** hierarchy in which classes **MyLine**, **MyOval** and **MyRect** subclass **MyShape** directly. If the hierarchy was properly designed, you should be able to see the tremendous similarities between the **MyOval** and **MyRect** classes. Redesign and reimplement the code for the **MyOval** and **MyRect** classes to "factor out" the common features into the **abstract** class **MyBoundedShape** to produce the hierarchy in Fig. 9.46.

Class **MyBoundedShape** should define two constructors that mimic the constructors of class **MyShape** and methods that calculate the upper-left *x*-coordinate, upper-left *y*-coordinate, *width* and *height*. No new data pertaining to the dimensions of the shapes should be defined in this class. Remember, the values needed to draw an oval or rectangle can be calculated from two *(x,y)* coordinates. If designed properly, the new **MyOval** and **MyRect** classes should each have two constructors and a **draw** method.

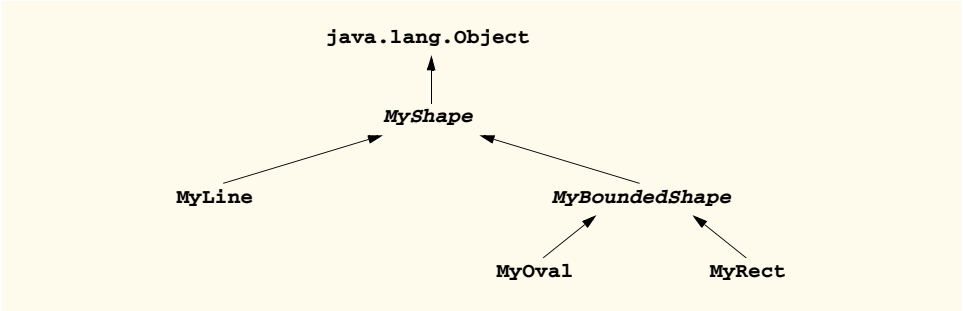

Fig. 9.46 The **MyShape** hierarchy.

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10

Strings and Characters

Objectives

- To be able to create and manipulate nonmodifiable character string objects of class **`String`**.
- To be able to create and manipulate modifiable character string objects of class **`StringBuffer`**.
- To be able to create and manipulate objects of class **`Character`**.
- To be able to use a **`StringTokenizer`** object to break a **`String`** object into individual components called tokens.

The chief defect of Henry King
Was chewing little bits of string.
Hilaire Belloc

Vigorous writing is concise. A sentence should contain no unnecessary words, a paragraph no unnecessary sentences.
William Strunk, Jr.

I have made this letter longer than usual, because I lack the time to make it short.
Blaise Pascal

The difference between the almost-right word & the right word is really a large matter—it's the difference between the lightning bug and the lightning.
Mark Twain

Mum's the word.
Miguel de Cervantes, *Don Quixote de la Mancha*

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Outline

10.1 Introduction
10.2 Fundamentals of Characters and Strings
10.3 `String` Constructors
10.4 `String` Methods `length`, `charAt` and `getChars`
10.5 Comparing `String`s
10.6 `String` Method `hashCode`
10.7 Locating Characters and Substrings in `String`s
10.8 Extracting Substrings from `String`s
10.9 Concatenating `String`s
10.10 Miscellaneous `String` Methods
10.11 Using `String` Method `valueOf`
10.12 `String` Method `intern`
10.13 `StringBuffer` Class
10.14 `StringBuffer` Constructors
10.15 `StringBuffer` Methods `length`, `capacity`, `setLength` and `ensureCapacity`
10.16 `StringBuffer` Methods `charAt`, `setCharAt`, `getChars` and `reverse`
10.17 `StringBuffer` `append` Methods
10.18 `StringBuffer` Insertion and Deletion Methods
10.19 `Character` Class Examples
10.20 Class `StringTokenizer`
10.21 Card Shuffling and Dealing Simulation
10.22 (Optional Case Study) Thinking About Objects: Event Handling

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises • Special Section: Advanced String Manipulation Exercises • Special Section: Challenging String Manipulation Projects

10.1 Introduction

In this chapter, we introduce Java's string and character-processing capabilities. The techniques discussed here are appropriate for validating program input, displaying information to users and other text-based manipulations. The techniques also are appropriate for developing text editors, word processors, page-layout software, computerized typesetting systems and other kinds of text-processing software. We have already presented several string-processing capabilities in the text. This chapter discusses in detail the capabilities of class ***`String`***, class ***`StringBuffer`*** and class ***`Character`*** from the **`java.lang`** package and class ***`StringTokenizer`*** from the **`java.util`** package. These classes provide the foundation for string and character manipulation in Java.

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10.2 Fundamentals of Characters and Strings

Characters are the fundamental building blocks of Java source programs. Every program is composed of a sequence of characters that—when grouped together meaningfully—is interpreted by the computer as a series of instructions used to accomplish a task. A program might contain *character constants.* A character constant is an integer value represented as a character in single quotes. As we stated previously, the value of a character constant is the integer value of the character in the *Unicode character set*. For example, **'z'** represents the integer value of **z**, and **'\n'** represents the integer value of newline. See Appendix D for the integer equivalents of these characters.

A string is a series of characters treated as a single unit. A string may include letters, digits and various *special characters,* such as **+**, **-**, *****, **/**, **$** and others. A string is an object of class **String**. *String literals* or *string constants* (often called *anonymous* ***String*** *objects*) are written as a sequence of characters in double quotation marks as follows:

```
"John Q. Doe"              (a name)
"9999 Main Street"         (a street address)
"Waltham, Massachusetts"   (a city and state)
"(201) 555-1212"           (a telephone number)
```

A **String** may be assigned in a declaration to a **String** reference. The declaration

```
String color = "blue";
```

initializes **String** reference **color** to refer to the anonymous **String** object **"blue"**.

Performance Tip 10.1

Java treats all anonymous ***String****s with the same contents as one anonymous* ***String*** *object that has many references. This conserves memory.*

10.3 String Constructors

Class **String** provides nine constructors for initializing **String** objects in a variety of ways. Seven of the constructors are demonstrated in Fig. 10.1. All the constructors are used in the **StringConstructors** application's **main** method.

Line 25 instantiates a new **String** object and assigns it to reference **s1**, using class **String**'s default constructor. The new **String** object contains no characters (the *empty string*) and has a length of 0.

Line 26 instantiates a new **String** object and assigns it to reference **s2**, using class **String**'s copy constructor. The new **String** object contains a copy of the characters in the **String** object **s** that is passed as an argument to the constructor.

```
1  // Fig. 10.1: StringConstructors.java
2  // This program demonstrates the String class constructors.
3
4  // Java extension packages
5  import javax.swing.*;
6
```

Fig. 10.1 Demonstrating the **String** class constructors (part 1 of 2).

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```
 7  public class StringConstructors {
 8
 9     // test String constructors
10     public static void main( String args[] )
11     {
12        char charArray[] = { 'b', 'i', 'r', 't', 'h', ' ',
13                             'd', 'a', 'y' };
14        byte byteArray[] = { ( byte ) 'n', ( byte ) 'e',
15           ( byte ) 'w', ( byte ) ' ', ( byte ) 'y',
16           ( byte ) 'e', ( byte ) 'a', ( byte ) 'r' };
17
18        StringBuffer buffer;
19        String s, s1, s2, s3, s4, s5, s6, s7, output;
20
21        s = new String( "hello" );
22        buffer = new StringBuffer( "Welcome to Java Programming!" );
23
24        // use String constructors
25        s1 = new String();
26        s2 = new String( s );
27        s3 = new String( charArray );
28        s4 = new String( charArray, 6, 3 );
29        s5 = new String( byteArray, 4, 4 );
30        s6 = new String( byteArray );
31        s7 = new String( buffer );
32
33        // append Strings to output
34        output = "s1 = " + s1 + "\ns2 = " + s2 + "\ns3 = " + s3 +
35           "\ns4 = " + s4 + "\ns5 = " + s5 + "\ns6 = " + s6 +
36           "\ns7 = " + s7;
37
38        JOptionPane.showMessageDialog( null, output,
39           "Demonstrating String Class Constructors",
40           JOptionPane.INFORMATION_MESSAGE );
41
42        System.exit( 0 );
43     }
44
45  }  // end class StringConstructors
```

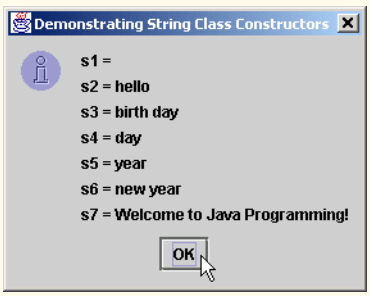

Fig. 10.1 Demonstrating the **`String`** class constructors (part 2 of 2).

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Software Engineering Observation 10.1

In most cases, it is not necessary to make a copy of an existing **`String`** *object.* **`String`** *objects are immutable—their character contents cannot be changed after they are created. Also, if there are one or more references to a* **`String`** *object (or any object for that matter), the object cannot be reclaimed by the garbage collector. Thus, a* **`String`** *reference cannot be used to modify a* **`String`** *object or to delete a* **`String`** *object from memory as in other programming languages, such as C or C++.*

Line 27 instantiates a new **`String`** object and assigns it to reference **`s3`** using class **`String`**'s constructor that takes a character array as an argument. The new **`String`** object contains a copy of the characters in the array.

Line 28 instantiates a new **`String`** object and assigns it to reference **`s4`** using class **`String`**'s constructor that takes a **`char`** array and two integers as arguments. The second argument specifies the starting position (the ***`offset`***) from which characters in the array are copied. The third argument specifies the number of characters (the ***`count`***) to be copied from the array. The new **`String`** object contains a copy of the specified characters in the array. If the **`offset`** or the **`count`** specified as arguments result in accessing an element outside the bounds of the character array, a **`StringIndexOutOfBoundsException`** is thrown. We discuss exceptions in detail in Chapter 14.

Line 29 instantiates a new **`String`** object and assigns it to reference **`s5`** using class **`String`**'s constructor that receives a **`byte`** array and two integers as arguments. The second and third arguments specify the **`offset`** and **`count`**, respectively. The new **`String`** object contains a copy of the specified **`byte`**s in the array. If the **`offset`** or the **`count`** specified as arguments result in accessing an element outside the bounds of the character array, a **`StringIndexOutOfBoundsException`** is thrown.

Line 30 instantiates a new **`String`** object and assigns it to reference **`s6`** using class **`String`**'s constructor that takes a **`byte`** array as an argument. The new **`String`** object contains a copy of the bytes in the array.

Line 31 instantiates a new **`String`** object and assigns it to reference **`s7`** using class **`String`**'s constructor that receives a **`StringBuffer`** as an argument. A **`StringBuffer`** is a dynamically resizable and modifiable string. The new **`String`** object contains a copy of the characters in the **`StringBuffer`**. Line 22 creates a new object of class **`StringBuffer`** using the constructor that receives a **`String`** argument (in this case **`"Welcome to Java Programming"`**) and assign the new object to reference **`buffer`**. We discuss **`StringBuffer`**s in detail later in this chapter. The screen capture for the program displays the contents of each **`String`**.

10.4 `String` Methods `length`, `charAt` and `getChars`

The application of Fig. 10.2 presents **`String`** methods ***`length`***, ***`charAt`*** and ***`getChars`***, which determine the length of a **`String`**, get the character at a specific location in a **`String`** and get the entire set of characters in a **`String`**, respectively.

Line 28 uses **`String`** method **`length`** to determine the number of characters in **`String`** **`s1`**. Like arrays, **`String`**s always know their own size. However, unlike arrays, **`String`**s do not have a **`length`** instance variable that specifies the number of elements in a **`String`**.

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```
1  // Fig. 10.2: StringMiscellaneous.java
2  // This program demonstrates the length, charAt and getChars
3  // methods of the String class.
4  //
5  // Note: Method getChars requires a starting point
6  // and ending point in the String. The starting point is the
7  // actual subscript from which copying starts. The ending point
8  // is one past the subscript at which the copying ends.
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class StringMiscellaneous {
14
15    // test miscellaneous String methods
16    public static void main( String args[] )
17    {
18       String s1, output;
19       char charArray[];
20
21       s1 = new String( "hello there" );
22       charArray = new char[ 5 ];
23
24       // output the string
25       output = "s1: " + s1;
26
27       // test length method
28       output += "\nLength of s1: " + s1.length();
29
30       // loop through characters in s1 and display reversed
31       output += "\nThe string reversed is: ";
32
33       for ( int count = s1.length() - 1; count >= 0; count-- )
34          output += s1.charAt( count ) + " ";
35
36       // copy characters from string into char array
37       s1.getChars( 0, 5, charArray, 0 );
38       output += "\nThe character array is: ";
39
40       for ( int count = 0; count < charArray.length; count++ )
41          output += charArray[ count ];
42
43       JOptionPane.showMessageDialog( null, output,
44          "Demonstrating String Class Constructors",
45          JOptionPane.INFORMATION_MESSAGE );
46
47       System.exit( 0 );
48    }
49
50 }  // end class StringMiscellaneous
```

Fig. 10.2 The **String** class character manipulation methods (part 1 of 2).

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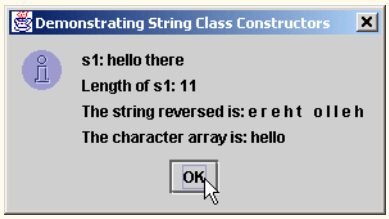

Fig. 10.2 The **`String`** class character manipulation methods (part 2 of 2).

Common Programming Error 10.1

Attempting to determine the length of a **`String`** *via an instance variable called* **`length`** *(e.g.,* **`s1.length`***) is a syntax error. The* **`String`** *method* **`length`** *must be used. (e.g.,* **`s1.length()`***).*

The **`for`** structure at lines 33–34 appends to **`output`** the characters of the **`String`** **`s1`** in reverse order. The **`String`** method **`charAt`** returns the character at a specific position in the **`String`**. Method **`charAt`** receives an integer argument that is used as the *position number* (or *index*) and returns the character at that position. Like arrays, the first element of a **`String`** is considered to be at position 0.

Common Programming Error 10.2

Attempting to access a character that is outside the bounds of a **`String`** *(i.e., an index less than 0 or an index greater than or equal to the* **`String`***'s length) results in a* **`StringIndexOutOfBoundsException`**.

Line 37 uses **`String`** method **`getChars`** to copy the characters of a **`String`** into a character array. The first argument is the starting index from which characters are copied in the **`String`**. The second argument is the index that is one past the last character to be copied from the **`String`**. The third argument is the character array into which the characters are copied. The last argument is the starting index where the copied characters are placed in the character array. Next, the **`char`** array contents are appended one character at a time to **`String`** **`output`** with the **`for`** structure at lines 40–41 for display purposes.

10.5 Comparing `String`s

Java provides a variety of methods for comparing **`String`** objects; these are demonstrated in the next two examples. To understand just what it means for one string to be "greater than" or "less than" another string, consider the process of alphabetizing a series of last names. The reader would, no doubt, place "Jones" before "Smith" because the first letter of "Jones" comes before the first letter of "Smith" in the alphabet. But the alphabet is more than just a list of 26 letters—it is an ordered list of characters. Each letter occurs in a specific position within the list. "Z" is more than just a letter of the alphabet; "Z" is specifically the twenty-sixth letter of the alphabet.

How does the computer know that one letter comes before another? All characters are represented inside the computer as numeric codes (see Appendix D). When the computer compares two strings, it actually compares the numeric codes of the characters in the strings.

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Figure 10.3 demonstrates the **`String`** methods ***`equals`***, ***`equalsIgnoreCase`***, ***`compareTo`*** and ***`regionMatches`*** and demonstrates using the equality operator **`==`** to compare **`String`** objects.

```
1  // Fig. 10.3: StringCompare.java
2  // This program demonstrates the methods equals,
3  // equalsIgnoreCase, compareTo, and regionMatches
4  // of the String class.
5
6  // Java extension packages
7  import javax.swing.JOptionPane;
8
9  public class StringCompare {
10
11    // test String class comparison methods
12    public static void main( String args[] )
13    {
14       String s1, s2, s3, s4, output;
15
16       s1 = new String( "hello" );
17       s2 = new String( "good bye" );
18       s3 = new String( "Happy Birthday" );
19       s4 = new String( "happy birthday" );
20
21       output = "s1 = " + s1 + "\ns2 = " + s2 +
22          "\ns3 = " + s3 + "\ns4 = " + s4 + "\n\n";
23
24       // test for equality
25       if ( s1.equals( "hello" ) )
26          output += "s1 equals \"hello\"\n";
27       else
28          output += "s1 does not equal \"hello\"\n";
29
30       // test for equality with ==
31       if ( s1 == "hello" )
32          output += "s1 equals \"hello\"\n";
33       else
34          output += "s1 does not equal \"hello\"\n";
35
36       // test for equality (ignore case)
37       if ( s3.equalsIgnoreCase( s4 ) )
38          output += "s3 equals s4\n";
39       else
40          output += "s3 does not equal s4\n";
41
42       // test compareTo
43       output +=
44          "\ns1.compareTo( s2 ) is " + s1.compareTo( s2 ) +
45          "\ns2.compareTo( s1 ) is " + s2.compareTo( s1 ) +
46          "\ns1.compareTo( s1 ) is " + s1.compareTo( s1 ) +
47          "\ns3.compareTo( s4 ) is " + s3.compareTo( s4 ) +
48          "\ns4.compareTo( s3 ) is " + s4.compareTo( s3 ) +
49          "\n\n";
```

Fig. 10.3 Demonstrating **`String`** comparisons (part 1 of 2).

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```
50
51          // test regionMatches (case sensitive)
52          if ( s3.regionMatches( 0, s4, 0, 5 ) )
53             output += "First 5 characters of s3 and s4 match\n";
54          else
55             output +=
56                "First 5 characters of s3 and s4 do not match\n";
57
58          // test regionMatches (ignore case)
59          if ( s3.regionMatches( true, 0, s4, 0, 5 ) )
60             output += "First 5 characters of s3 and s4 match";
61          else
62             output +=
63                "First 5 characters of s3 and s4 do not match";
64
65          JOptionPane.showMessageDialog( null, output,
66             "Demonstrating String Class Constructors",
67             JOptionPane.INFORMATION_MESSAGE );
68
69          System.exit( 0 );
70       }
71
72    }  // end class StringCompare
```

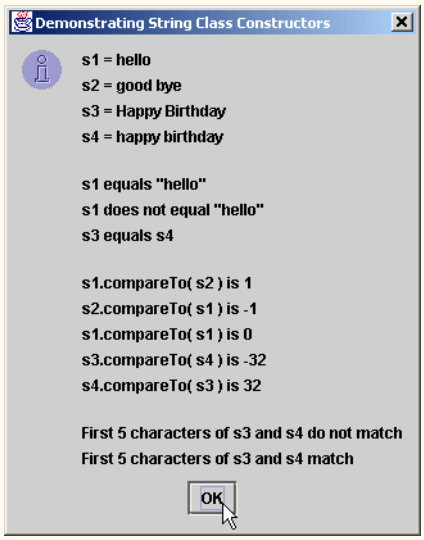

Fig. 10.3 Demonstrating **`String`** comparisons (part 2 of 2).

The condition in the **`if`** structure at line 25 uses method **`equals`** to compare **`String s1`** and anonymous **`String "hello"`** for equality. Method **`equals`** (inherited into **`String`** from its superclass **`Object`**) tests any two objects for equality—the contents of the two objects are identical. The method returns **`true`** if the objects are equal and **`false`** otherwise. The preceding condition is **`true`** because **`String s1`** was initialized with a copy of the anonymous **`String "hello"`**. Method **`equals`** uses a *lexicographical comparison*—the integer Unicode values that represent each character in each **`String`** are

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compared. Thus, if the **`String "hello"`** is compared with the **`String "HELLO"`**, the result is **`false`**, because the integer representation of a lowercase letter is different from that of the corresponding uppercase letter.

The condition in the **`if`** structure at line 31 uses the equality operator **`==`** to compare **`String s1`** for equality with the anonymous **`String "hello"`**. *Operator == has different functionality when it is used to compare references and when it is used to compare values of primitive data types.* When primitive data type values are compared with **`==`**, the result is **`true`** if both values are identical. When references are compared with **`==`**, the result is **`true`** if both references *refer to the same object in memory*. To compare the actual contents (or state information) of objects for equality, methods (such as **`equals`**) must be invoked. The preceding condition evaluates to **`false`** in this program because the reference **`s1`** was initialized with the statement

```
s1 = new String( "hello" );
```

which creates a new **`String`** object with a copy of anonymous **`String "hello"`** and assigns the new object to reference **`s1`**. If **`s1`** had been initialized with the statement

```
s1 = "hello";
```

which directly assigns the anonymous **`String "hello"`** to the reference **`s1`**, the condition would be **`true`**. Remember that Java treats all anonymous **`String`** objects with the same contents as one anonymous **`String`** object that has many references. Thus, lines 16, 25 and 31 all refer to the same anonymous **`String`** object **`"hello"`** in memory.

Common Programming Error 10.3

*Comparing references with **`==`** can lead to logic errors, because **`==`** compares the references to determine whether they refer to the same object, not whether two objects have the same contents. When two identical (but separate) objects are compared with **`==`**, the result will be **`false`**. When comparing objects to determine whether they have the same contents, use method **`equals`**.*

If you are sorting **`String`**s, you may compare them for equality with method **`equalsIgnoreCase`**, which ignores the case of the letters in each **`String`** when performing the comparison. Thus, the **`String "hello"`** and the **`String "HELLO"`** compare as equal. The **`if`** structure at line 37 uses **`String`** method **`equalsIgnoreCase`** to compare **`String s3`**—**`Happy Birthday`**—for equality with **`String s4`**—**`happy birthday`**. The result of this comparison is **`true`**, because the comparison ignores case sensitivity.

Lines 44–48 use **`String`** method **`compareTo`** to compare **`String`** objects. For example, line 44 compares **`String s1`** to **`String s2`**. Method **`compareTo`** returns 0 if the **`Strings`** are equal, a negative number if the **`String`** that invokes **`compareTo`** is less than the **`String`** that is passed as an argument and a positive number if the **`String`** that invokes **`compareTo`** is greater than the **`String`** that is passed as an argument. Method **`compareTo`** uses a *lexicographical comparison*—it compares the numeric values of corresponding characters in each **`String`**.

The condition in the **`if`** structure at line 52 uses **`String`** method **`regionMatches`** to compare portions of two **`String`** objects for equality. The first argument is the starting index in the **`String`** that invokes the method. The second argument is a comparison

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String. The third argument is the starting index in the comparison **String**. The last argument is the number of characters to compare between the two **String**s. The method returns **true** only if the specified number of characters are lexicographically equal.

Finally, the condition in the **if** structure at line 59 uses a second version of **String** method **regionMatches** to compare portions of two **String** objects for equality. If the first argument is **true**, the method ignores the case of the characters being compared. The remaining arguments are identical to those described for the for-argument **regionMatches** method.

The second example of this section (Fig. 10.4) demonstrates the ***startsWith*** and ***endsWith*** methods of class **String**. Application **StringStartEnd**'s **main** method defines an array of **String**s called **strings** containing **"started"**, **"starting"**, **"ended"** and **"ending"**. The remainder of method **main** consists of three **for** structures that test the elements of the array to determine whether they start with or end with a particular set of characters.

```
1  // Fig. 10.4: StringStartEnd.java
2  // This program demonstrates the methods startsWith and
3  // endsWith of the String class.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringStartEnd {
9
10    // test String comparison methods for beginning and end
11    // of a String
12    public static void main( String args[] )
13    {
14       String strings[] =
15          { "started", "starting", "ended", "ending" };
16       String output = "";
17
18       // test method startsWith
19       for ( int count = 0; count < strings.length; count++ )
20
21          if ( strings[ count ].startsWith( "st" ) )
22             output += "\"" + strings[ count ] +
23                "\" starts with \"st\"\n";
24
25       output += "\n";
26
27       // test method startsWith starting from position
28       // 2 of the string
29       for ( int count = 0; count < strings.length; count++ )
30
31          if ( strings[ count ].startsWith( "art", 2 ) )
32             output += "\"" + strings[ count ] +
33                "\" starts with \"art\" at position 2\n";
34
35       output += "\n";
```

Fig. 10.4 **String** class **startsWith** and **endsWith** methods (part 1 of 2).

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```
36
37          // test method endsWith
38          for ( int count = 0; count < strings.length; count++ )
39
40             if ( strings[ count ].endsWith( "ed" ) )
41                output += "\"" + strings[ count ] +
42                   "\" ends with \"ed\"\n";
43
44          JOptionPane.showMessageDialog( null, output,
45             "Demonstrating String Class Comparisons",
46             JOptionPane.INFORMATION_MESSAGE );
47
48          System.exit( 0 );
49       }
50
51    }  // end class StringStartEnd
```

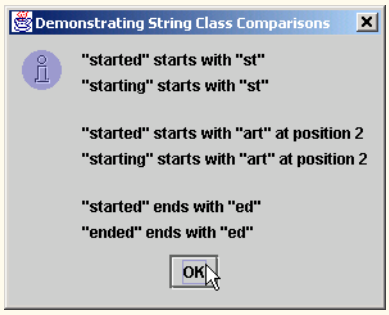

Fig. 10.4 **`String`** class **`startsWith`** and **`endsWith`** methods (part 2 of 2).

The first **`for`** structure (lines 19–23) uses the version of method **`startsWith`** that takes a **`String`** argument. The condition in the **`if`** structure (line 21) determines whether the **`String`** at location **`count`** of the array starts with the characters **`"st"`**. If so, the method returns **`true`** and the program appends **`strings[ count ]`** to **`output`** for display purposes.

The second **`for`** structure (lines 29–33) uses the version of method **`startsWith`** that takes a **`String`** and an integer as arguments. The integer argument specifies the index at which the comparison should begin in the **`String`**. The condition in the **`if`** structure (line 31) determines whether the **`String`** at location **`count`** of the array starts with the characters **`"art"`** beginning with the character at index **`2`** in each **`String`**. If so, the method returns **`true`** and the program appends **`strings[ count ]`** to **`output`** for display purposes.

The third **`for`** structure (line 38–42) uses method **`endsWith`**, which takes a **`String`** argument. The condition in the **`if`** structure (40) determines whether the **`String`** at location **`count`** of the array ends with the characters **`"ed"`**. If so, the method returns **`true`** and the program appends **`strings[ count ]`** to **`output`** for display purposes.

10.6 `String` Method `hashCode`

Often, it is necessary to store **`String`**s and other data types in a manner that allows the information to be found quickly. One of the best ways to store information for fast lookup

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is a *hash table*. A hash table stores information using a special calculation on the object to be stored that produces a *hash code*. The hash code is used to choose the location in the table at which to store the object. When the information needs to be retrieved, the same calculation is performed, the hash code is determined and a lookup of that location in the table results in the value that was stored there previously. Every object has the ability to be stored in a hash table. Class **`Object`** defines method ***`hashCode`*** to perform the hash code calculation. This method is inherited by all subclasses of **`Object`**. Method **`hashCode`** is overridden by **`String`** to provide a good hash code distribution based on the contents of the **`String`**. We will say more about hashing in Chapter 20.

The example in Fig. 10.5 demonstrates the **`hashCode`** method for two **`String`**s containing **`"hello"`** and **`"Hello"`**. Note that the hash code value for each **`String`** is different. That is because the **`String`**s themselves are lexicographically different.

```
1  // Fig. 10.5: StringHashCode.java1
2  // This program demonstrates the method
3  // hashCode of the String class.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringHashCode {
9
10    // test String hashCode method
11    public static void main( String args[] )
12    {
13       String s1 = "hello", s2 = "Hello";
14
15       String output =
16          "The hash code for \"" + s1 + "\" is " +
17          s1.hashCode() +
18          "\nThe hash code for \"" + s2 + "\" is " +
19          s2.hashCode();
20
21       JOptionPane.showMessageDialog( null, output,
22          "Demonstrating String Method hashCode",
23          JOptionPane.INFORMATION_MESSAGE );
24
25       System.exit( 0 );
26    }
27
28 }  // end class StringHashCode
```

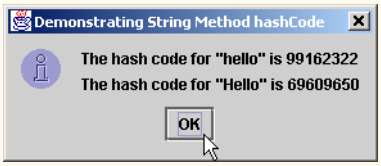

Fig. 10.5 **`String`** class **`hashCode`** method.

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10.7 Locating Characters and Substrings in `String`s

Often it is useful to search for a character or set of characters in a **`String`**. For example, if you are creating your own word processor, you might want to provide a capability for searching through the document. The application of Fig. 10.6 demonstrates the many versions of **`String`** methods ***`indexOf`*** and ***`lastIndexOf`*** that search for a specified character or substring in a **`String`**. All the searches in this example are performed on the **`String letters`** (initialized with **`"abcdefghijklmabcdefghijklm"`**) in method **`main`** of class **`StringIndexMethods`**.

```
1  // Fig. 10.6: StringIndexMethods.java
2  // This program demonstrates the String
3  // class index methods.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringIndexMethods {
9
10    // String searching methods
11    public static void main( String args[] )
12    {
13       String letters = "abcdefghijklmabcdefghijklm";
14
15       // test indexOf to locate a character in a string
16       String output = "'c' is located at index " +
17          letters.indexOf( 'c' );
18
19       output += "\n'a' is located at index " +
20          letters.indexOf( 'a', 1 );
21
22       output += "\n'$' is located at index " +
23          letters.indexOf( '$' );
24
25       // test lastIndexOf to find a character in a string
26       output += "\n\nLast 'c' is located at index " +
27          letters.lastIndexOf( 'c' );
28
29       output += "\nLast 'a' is located at index " +
30          letters.lastIndexOf( 'a', 25 );
31
32       output += "\nLast '$' is located at index " +
33          letters.lastIndexOf( '$' );
34
35       // test indexOf to locate a substring in a string
36       output += "\n\n\"def\" is located at index " +
37          letters.indexOf( "def" );
38
39       output += "\n\"def\" is located at index " +
40          letters.indexOf( "def", 7 );
41
```

Fig. 10.6 The **`String`** class searching methods (part 1 of 2).

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```
42          output += "\n\"hello\" is located at index " +
43             letters.indexOf( "hello" );
44
45          // test lastIndexOf to find a substring in a string
46          output += "\n\nLast \"def\" is located at index " +
47             letters.lastIndexOf( "def" );
48
49          output += "\nLast \"def\" is located at index " +
50             letters.lastIndexOf( "def", 25 );
51
52          output += "\nLast \"hello\" is located at index " +
53             letters.lastIndexOf( "hello" );
54
55          JOptionPane.showMessageDialog( null, output,
56             "Demonstrating String Class \"index\" Methods",
57             JOptionPane.INFORMATION_MESSAGE );
58
59          System.exit( 0 );
60       }
61
62    }  // end class StringIndexMethods
```

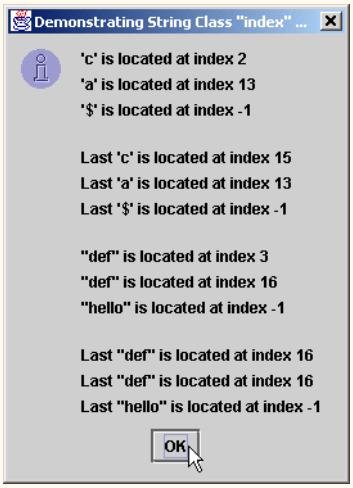

Fig. 10.6 The **`String`** class searching methods (part 2 of 2).

The statements at lines 16–23 use method **`indexOf`** to locate the first occurrence of a character in a **`String`**. If **`indexOf`** finds the character, **`indexOf`** returns the index of that character in the **`String`**; otherwise, **`indexOf`** returns –1. There are two versions of **`indexOf`** that search for characters in a **`String`**. The expression on line 17 uses method **`indexOf`** that takes one integer argument, which is the integer representation of a character. Remember that a character constant in single quotes is of type **`char`** and specifies the integer representation of the character in the Unicode character set. The expression at line 20 uses the second version of method **`indexOf`**, which takes two integer arguments—the integer representation of a character and the starting index at which the search of the **`String`** should begin.

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The statements at lines 26–33 use method **lastIndexOf** to locate the last occurrence of a character in a **String**. Method **lastIndexOf** performs the search from the end of the **String** toward the beginning of the **String**. If method **lastIndexOf** finds the character, **lastIndexOf** returns the index of that character in the **String**; otherwise, **lastIndexOf** returns –1. There are two versions of **lastIndexOf** that search for characters in a **String**. The expression at line 27 uses the version of method **lastIndexOf** that takes one integer argument that is the integer representation of a character. The expression at line 30 uses the version of method **lastIndexOf** that takes two integer arguments—the integer representation of a character and the highest index from which to begin searching backward for the character.

Lines 36–53 of the program demonstrate versions of methods **indexOf** and **lastIndexOf** that each take a **String** as the first argument. These versions of the methods perform identically to those described above except that they search for sequences of characters (or substrings) that are specified by their **String** arguments.

10.8 Extracting Substrings from `Strings`

Class **String** provides two ***substring*** methods to enable a new **String** object to be created by copying part of an existing **String** object. Each method returns a new **String** object. Both methods are demonstrated in Fig. 10.7.

```
1  // Fig. 10.7: SubString.java
2  // This program demonstrates the
3  // String class substring methods.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class SubString {
9
10    // test String substring methods
11    public static void main( String args[] )
12    {
13       String letters = "abcdefghijklmabcdefghijklm";
14
15       // test substring methods
16       String output = "Substring from index 20 to end is " +
17          "\"" + letters.substring( 20 ) + "\"\n";
18
19       output += "Substring from index 0 up to 6 is " +
20          "\"" + letters.substring( 0, 6 ) + "\"";
21
22       JOptionPane.showMessageDialog( null, output,
23          "Demonstrating String Class Substring Methods",
24          JOptionPane.INFORMATION_MESSAGE );
25
26       System.exit( 0 );
27    }
28
29 }  // end class SubString
```

Fig. 10.7 **String** class **substring** methods (part 1 of 2).

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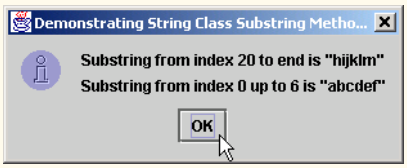

Fig. 10.7 **String** class **substring** methods (part 2 of 2).

The expression **letters.substring(20)** from line 17 uses the **substring** method that takes one integer argument. The argument specifies the starting index from which characters are copied in the original **String**. The substring returned contains a copy of the characters from the starting index to the end of the **String**. If the index specified as an argument is outside the bounds of the **String**, the program generates a **StringIndexOutOfBoundsException**.

The expression **letters.substring(0, 6)** from line 17 uses the **substring** method that takes two integer arguments. The first argument specifies the starting index from which characters are copied in the original **String**. The second argument specifies the index one beyond the last character to be copied (i.e., copy up to, but not including, that index in the **String**). The substring returned contains copies of the specified characters from the original **String**. If the arguments are outside the bounds of the **String**, the program generates a **StringIndexOutOfBoundsException**.

10.9 Concatenating Strings

The **String** method **concat** (Fig. 10.8) concatenates two **String** objects and returns a new **String** object containing the characters from both original **String**s. If the argument **String** has no characters in it, the original **String** is returned. The expression **s1.concat(s2)** at line 20 appends the characters from the **String s2** to the end of the **String s1**. The original **String**s to which **s1** and **s2** refer are not modified.

Performance Tip 10.2

*In programs that frequently perform **String** concatenation, or other **String** modifications, it is more efficient to implement those modifications with class **StringBuffer** (covered in Section 10.13–Section 10.18).*

```
1  // Fig. 10.8: StringConcatenation.java
2  // This program demonstrates the String class concat method.
3  // Note that the concat method returns a new String object. It
4  // does not modify the object that invoked the concat method.
5
6  // Java extension packages
7  import javax.swing.*;
8
9  public class StringConcatenation {
10
```

Fig. 10.8 **String** method **concat** (part 1 of 2).

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```
11      // test String method concat
12      public static void main( String args[] )
13      {
14         String s1 = new String( "Happy " ),
15                s2 = new String( "Birthday" );
16
17         String output = "s1 = " + s1 + "\ns2 = " + s2;
18
19         output += "\n\nResult of s1.concat( s2 ) = " +
20            s1.concat( s2 );
21
22         output += "\ns1 after concatenation = " + s1;
23
24         JOptionPane.showMessageDialog( null, output,
25            "Demonstrating String Method concat",
26            JOptionPane.INFORMATION_MESSAGE );
27
28         System.exit( 0 );
29      }
30
31   }  // end class StringConcatenation
```

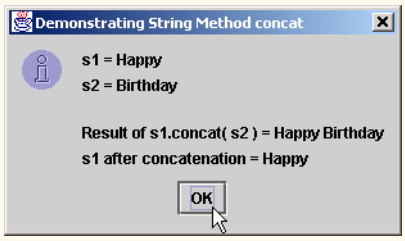

Fig. 10.8 **`String`** method **`concat`** (part 2 of 2).

10.10 Miscellaneous `String` Methods

Class **`String`** provides several methods that return modified copies of **`String`**s or that return a character array. These methods are demonstrated in the application of Fig. 10.9.

Line 22 uses **`String`** method **`replace`** to return a new **`String`** object in which the method replaces every occurrence in **`String s1`** of character **`'l'`** (el) with character **`'L'`**. Method **`replace`** leaves the original **`String`** unchanged. If there are no occurrences of the first argument in the **`String`**, Method **`replace`** returns the original **`String`**.

Line 26 uses **`String`** method **`toUpperCase`** to generate a new **`String`** object with uppercase letters where corresponding lowercase letters reside in **`s1`**. The method returns a new **`String`** object containing the converted **`String`** and leaves the original **`String`** unchanged. If there are no characters to convert to uppercase letters, method **`toUpperCase`** returns the original **`String`**.

Line 27 uses **`String`** method **`toLowerCase`** to return a new **`String`** object with lowercase letters where corresponding uppercase letters reside in **`s1`**. The original **`String`** remains unchanged. If there are no characters to convert to lowercase letters, method **`toLowerCase`** returns the original **`String`**.

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```
1  // Fig. 10.9: StringMiscellaneous2.java
2  // This program demonstrates the String methods replace,
3  // toLowerCase, toUpperCase, trim, toString and toCharArray
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringMiscellaneous2 {
9
10    // test miscellaneous String methods
11    public static void main( String args[] )
12    {
13       String s1 = new String( "hello" ),
14          s2 = new String( "GOOD BYE" ),
15          s3 = new String( "   spaces   " );
16
17       String output = "s1 = " + s1 + "\ns2 = " + s2 +
18          "\ns3 = " + s3;
19
20       // test method replace
21       output += "\n\nReplace 'l' with 'L' in s1: " +
22          s1.replace( 'l', 'L' );
23
24       // test toLowerCase and toUpperCase
25       output +=
26          "\n\ns1.toUpperCase() = " + s1.toUpperCase() +
27          "\ns2.toLowerCase() = " + s2.toLowerCase();
28
29       // test trim method
30       output += "\n\ns3 after trim = \"" + s3.trim() + "\"";
31
32       // test toString method
33       output += "\n\ns1 = " + s1.toString();
34
35       // test toCharArray method
36       char charArray[] = s1.toCharArray();
37
38       output += "\n\ns1 as a character array = ";
39
40       for ( int count = 0; count < charArray.length; ++count )
41          output += charArray[ count ];
42
43       JOptionPane.showMessageDialog( null, output,
44          "Demonstrating Miscellaneous String Methods",
45          JOptionPane.INFORMATION_MESSAGE );
46
47       System.exit( 0 );
48    }
49
50 }  // end class StringMiscellaneous2
```

Fig. 10.9 Miscellaneous **`String`** methods (part 1 of 2).

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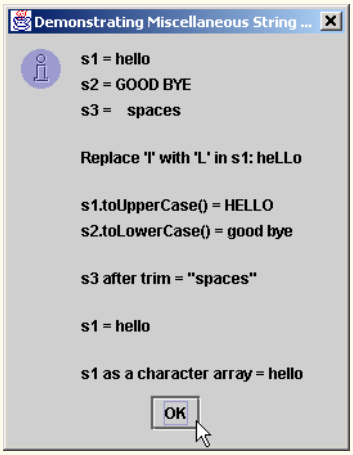

Fig. 10.9 Miscellaneous **`String`** methods (part 2 of 2).

Line 30 uses **`String`** method **`trim`** to generate a new **`String`** object that removes all white-space characters that appear at the beginning or end of the **`String`** to which the **`trim`** message is sent. The method returns a new **`String`** object containing the **`String`** without leading or trailing white-space characters. The original **`String`** remains unchanged.

Line 33 uses **`String`** method **`toString`** to return the **`String s1`**. Why is the **`toString`** method provided for class **`String`**? All objects can be converted to **`String`**s in Java by using method **`toString`**, which originates in class **`Object`**. If a class that inherits from **`Object`** (such as **`String`**) does not override method **`toString`**, the default version from class **`Object`** is used. The default version in **`Object`** creates a **`String`** consisting of the object's class name and the hash code for the object. The **`toString`** method normally is used to express the contents of an object as text. Method **`toString`** is provided in class **`String`** to ensure that the proper **`String`** value is returned.

Line 36 creates a new character array containing a copy of the characters in **`String s1`** and assigns it to **`charArray`**.

10.11 Using `String` Method `valueOf`

Class **`String`** provides a set of **`static`** class methods that take arguments of various types, convert those arguments to **`String`**s and return them as **`String`** objects. Class **`StringValueOf`** (Fig. 10.10) demonstrates the **`String`** class ***`valueOf`*** methods.

```
1  // Fig. 10.10: StringValueOf.java
2  // This program demonstrates the String class valueOf methods.
3
4  // Java extension packages
5  import javax.swing.*;
6
```

Fig. 10.10 **`String`** class **`valueOf`** methods (part 1 of 2).

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```
 7  public class StringValueOf {
 8
 9     // test String valueOf methods
10     public static void main( String args[] )
11     {
12        char charArray[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
13        boolean b = true;
14        char c = 'Z';
15        int i = 7;
16        long l = 10000000;
17        float f = 2.5f;
18        double d = 33.333;
19
20        Object o = "hello";  // assign to an Object reference
21        String output;
22
23        output = "char array = " + String.valueOf( charArray ) +
24           "\npart of char array = " +
25           String.valueOf( charArray, 3, 3 ) +
26           "\nboolean = " + String.valueOf( b ) +
27           "\nchar = " + String.valueOf( c ) +
28           "\nint = " + String.valueOf( i ) +
29           "\nlong = " + String.valueOf( l ) +
30           "\nfloat = " + String.valueOf( f ) +
31           "\ndouble = " + String.valueOf( d ) +
32           "\nObject = " + String.valueOf( o );
33
34        JOptionPane.showMessageDialog( null, output,
35           "Demonstrating String Class valueOf Methods",
36           JOptionPane.INFORMATION_MESSAGE );
37
38        System.exit( 0 );
39     }
40
41  }  // end class StringValueOf
```

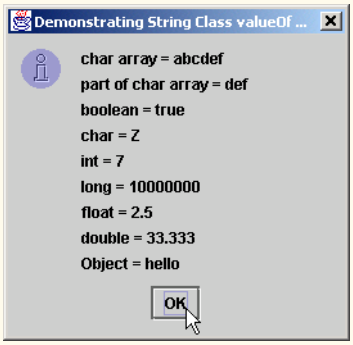

Fig. 10.10 **`String`** class **`valueOf`** methods (part 2 of 2).

The expression **`String.valueOf( charArray )`** from line 23 copies the contents of the character array **`charArray`** into a new **`String`** object and returns the new **`String`**. The expression **`String.valueOf( charArray, 3, 3 )`** from line 25

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copies a portion of the contents of the character array **charArray** into a new **String** object and returns the new **String**. The second argument specifies the starting index from which the characters are copied. The third argument specifies the number of characters to copy.

There are seven other versions of method **valueOf**, which take arguments of type **boolean**, **char**, **int**, **long**, **float**, **double** and **Object**, respectively. These are demonstrated in lines 26–32 of the program. Note that the version of **valueOf** that takes an **Object** as an argument can do so because all **Object**s can be converted to **String**s with method **toString**.

10.12 String Method intern

Comparing large **String** objects is a relatively slow operation. **String** method ***intern*** can improve **String** comparison performance. When **String** method **intern** is invoked on a **String** object, it returns a reference to a **String** object that is guaranteed to have the same contents as the original **String**. Class **String** maintains the resulting **String** during program execution. Subsequently, if the program invokes method **intern** on other **String** objects with contents identical to the original **String**, method **intern** returns a reference to the copy of the **String** maintained in memory by class **String**. If a program uses **intern** on extremely large **String**s, the program can compare those **String**s faster by using the **==** operator, which simply compares two references—a fast operation. Using standard **String** methods such as **equals** and **equalsIgnoreCase** can be slower, because they compare corresponding characters in each **String**. For large **String**s, this is a time-consuming, iterative operation. The program of Fig. 10.11 demonstrates the **intern** method.

The program declares five **String** references—**s1**, **s2**, **s3**, **s4** and **output**. **String**s **s1** and **s2** are initialized with new **String** objects that each contain a copy of **"hello"**. The first **if** structure (lines 20–23) uses operator **==** to determine that **String**s **s1** and **s2** are the same object. References **s1** and **s2** refer to different objects, because they were initialized with new **String** objects.

The second **if** structure (lines 26–29) uses method **equals** to determine that the contents of **String**s **s1** and **s2** are equal. They were each initialized with copies of **"hello"**, so they have the same contents.

```
1  // Fig. 10.11: StringIntern.java
2  // This program demonstrates the intern method
3  // of the String class.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringIntern {
9
10    // test String method intern
11    public static void main( String args[] )
12    {
13       String s1, s2, s3, s4, output;
```

Fig. 10.11 **String** class **intern** method (part 1 of 3).

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```
14
15          s1 = new String( "hello" );
16          s2 = new String( "hello" );
17
18          // test strings to determine if they are same
19          // String object in memory
20          if ( s1 == s2 )
21             output = "s1 and s2 are the same object in memory";
22          else
23             output = "s1 and s2 are not the same object in memory";
24
25          // test strings for equality of contents
26          if ( s1.equals( s2 ) )
27             output += "\ns1 and s2 are equal";
28          else
29             output += "\ns1 and s2 are not equal";
30
31          // use String intern method to get a unique copy of
32          // "hello" referred to by both s3 and s4
33          s3 = s1.intern();
34          s4 = s2.intern();
35
36          // test strings to determine if they are same
37          // String object in memory
38          if ( s3 == s4 )
39             output += "\ns3 and s4 are the same object in memory";
40          else
41             output +=
42                "\ns3 and s4 are not the same object in memory";
43
44          // determine if s1 and s3 refer to same object
45          if ( s1 == s3 )
46             output +=
47                "\ns1 and s3 are the same object in memory";
48          else
49             output +=
50                "\ns1 and s3 are not the same object in memory";
51
52          // determine if s2 and s4 refer to same object
53          if ( s2 == s4 )
54             output += "\ns2 and s4 are the same object in memory";
55          else
56             output +=
57                "\ns2 and s4 are not the same object in memory";
58
59          // determine if s1 and s4 refer to same object
60          if ( s1 == s4 )
61             output += "\ns1 and s4 are the same object in memory";
62          else
63             output +=
64                "\ns1 and s4 are not the same object in memory";
65
```

Fig. 10.11 **`String`** class **`intern`** method (part 2 of 3).

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```
66          JOptionPane.showMessageDialog( null, output,
67             "Demonstrating String Method intern",
68             JOptionPane.INFORMATION_MESSAGE );
69
70          System.exit( 0 );
71       }
72
73    }  // end class StringIntern
```

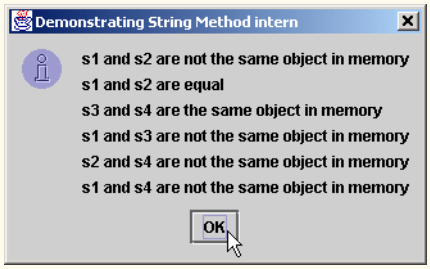

Fig. 10.11 **`String`** class **`intern`** method (part 3 of 3).

Line 33 uses method **`intern`** to get a reference to a **`String`** with the same contents as object **`s1`** and assigns the reference to **`s3`**. The **`String`** to which s3 refers is maintained in memory by class **`String`**. Line 34 also uses method **`intern`** to get a reference to a **`String`** object. However, because **`String s1`** and **`String s2`** have the same contents, the reference returned by this call to **`intern`** is a reference to the same **`String`** object returned by **`s1.intern()`**. The third **`if`** structure (lines 38–42) uses operator **`==`** to determine that **`String`**s **`s3`** and **`s4`** refer to the same object.

The fourth **`if`** structure (lines 45–50) uses operator **`==`** to determine that **`String`**s **`s1`** and **`s3`** are *not* the same object. Technically, they could refer to the same object, but they are not guaranteed to refer to the same object unless the objects they refer to were returned by calls to **`intern`** on **`String`**s with the same contents. In this case, **`s1`** refers to the **`String`** it was assigned in method **`main`** and **`s3`** refers to the **`String`** with the same contents maintained by class **`String`**.

The fifth **`if`** structure (lines 53–57) uses operator **`==`** to determine that **`String`**s **`s2`** and **`s4`** are *not* the same object, because the second **`intern`** call results in a reference to the same object returned by **`s1.intern()`**, not **`s2`**. Similarly, the sixth **`if`** structure (lines 60–64) uses operator **`==`** to determine that **`String`**s **`s1`** and **`s4`** are not the same object, because the second **`intern`** call results in a reference to the same object returned by **`s1.intern()`**, not **`s1`**.

10.13 `StringBuffer` Class

The **`String`** class provides many capabilities for processing **`String`**s. However, once a **`String`** object is created, its contents can never change. The next several sections discuss the features of class **`StringBuffer`** for creating and manipulating dynamic string information—i.e., modifiable **`String`**s. Every **`StringBuffer`** is capable of storing a number of characters specified by its capacity. If the capacity of a **`StringBuffer`** is exceeded, the capacity is automatically expanded to accommodate the additional charac-

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ters. As we will see, class **StringBuffer** is also used to implement operators **+** and **+=** for **String** concatenation.

Performance Tip 10.3

String *objects are constant strings and* ***StringBuffer*** *objects are modifiable strings. Java distinguishes constant strings from modifiable strings for optimization purposes; in particular, Java can perform certain optimizations involving* ***String*** *objects (such as sharing one* ***String*** *object among multiple references) because it knows these objects will not change.*

Performance Tip 10.4

When given the choice between using a ***String*** *object to represent a string versus a* ***StringBuffer*** *object to represent that string, always use a* ***String*** *object if indeed the object will not change; this improves performance.*

Common Programming Error 10.4

Invoking ***StringBuffer*** *methods that are not methods of class* ***String*** *on* ***String*** *objects is a syntax error.*

10.14 StringBuffer Constructors

Class **StringBuffer** provides three constructors (demonstrated in Fig. 10.12). Line 14 uses the default **StringBuffer** constructor to create a **StringBuffer** with no characters in it and an initial capacity of 16 characters. Line 15 uses **StringBuffer** constructor that takes an integer argument to create a **StringBuffer** with no characters in it and the initial capacity specified in the integer argument (i.e., **10**). Line 16 uses the **StringBuffer** constructor that takes a **String** argument to create a **StringBuffer** containing the characters of the **String** argument. The initial capacity is the number of characters in the **String** argument plus 16.

The statement on lines 18–21 uses **StringBuffer** method **toString** to convert the **StringBuffer**s into **String** objects that can be displayed with **drawString**. Note the use of operator **+** to concatenate **String**s for output. In Section 10.17, we discuss how Java uses **StringBuffer**s to implement the **+** and **+=** operators for **String** concatenation.

```
1  // Fig. 10.12: StringBufferConstructors.java
2  // This program demonstrates the StringBuffer constructors.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class StringBufferConstructors {
8
9     // test StringBuffer constructors
10    public static void main( String args[] )
11    {
12       StringBuffer buffer1, buffer2, buffer3;
13
```

Fig. 10.12 **StringBuffer** class constructors (part 1 of 2).

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```
14         buffer1 = new StringBuffer();
15         buffer2 = new StringBuffer( 10 );
16         buffer3 = new StringBuffer( "hello" );
17
18         String output =
19            "buffer1 = \"" + buffer1.toString() + "\"" +
20            "\nbuffer2 = \"" + buffer2.toString() + "\"" +
21            "\nbuffer3 = \"" + buffer3.toString() + "\"";
22
23         JOptionPane.showMessageDialog( null, output,
24            "Demonstrating StringBuffer Class Constructors",
25            JOptionPane.INFORMATION_MESSAGE );
26
27         System.exit( 0 );
28      }
29
30   }  // end class StringBufferConstructors
```

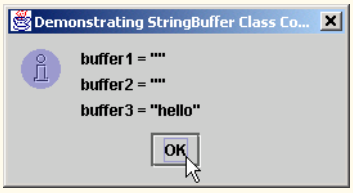

Fig. 10.12 **StringBuffer** class constructors (part 2 of 2).

10.15 StringBuffer Methods length, capacity, setLength and ensureCapacity

Class **StringBuffer** provides the **length** and **capacity** methods to return the number of characters currently in a **StringBuffer** and the number of characters that can be stored in a **StringBuffer** without allocating more memory, respectively. Method **ensureCapacity** is provided to allow the programmer to guarantee that a **StringBuffer** has a minimum capacity. Method **setLength** is provided to enable the programmer to increase or decrease the length of a **StringBuffer**. The program of Fig. 10.13 demonstrates these methods.

```
1  // Fig. 10.13: StringBufferCapLen.java
2  // This program demonstrates the length and
3  // capacity methods of the StringBuffer class.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringBufferCapLen {
9
10    // test StringBuffer methods for capacity and length
11    public static void main( String args[] )
12    {
```

Fig. 10.13 **StringBuffer length** and **capacity** methods (part 1 of 2).

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```
13          StringBuffer buffer =
14             new StringBuffer( "Hello, how are you?" );
15
16          String output = "buffer = " + buffer.toString() +
17             "\nlength = " + buffer.length() +
18             "\ncapacity = " + buffer.capacity();
19
20          buffer.ensureCapacity( 75 );
21          output += "\n\nNew capacity = " + buffer.capacity();
22
23          buffer.setLength( 10 );
24          output += "\n\nNew length = " + buffer.length() +
25             "\nbuf = " + buffer.toString();
26
27          JOptionPane.showMessageDialog( null, output,
28             "StringBuffer length and capacity Methods",
29             JOptionPane.INFORMATION_MESSAGE );
30
31          System.exit( 0 );
32       }
33
34    }  // end class StringBufferCapLen
```

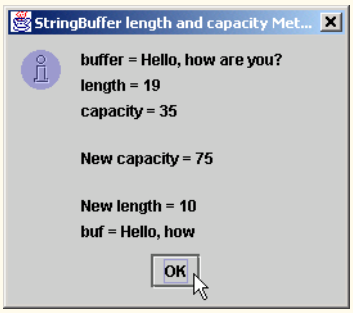

Fig. 10.13 **`StringBuffer`** **`length`** and **`capacity`** methods (part 2 of 2).

The program contains one **`StringBuffer`** called **`buffer`**. Lines 13–14 of the program use the **`StringBuffer`** constructor that takes a **`String`** argument to instantiate and initialize the **`StringBuffer`** with **`"Hello, how are you?"`**. Lines 16–18 append to **`output`** the contents, the length and the capacity of the **`StringBuffer`**. Notice in the output window that the capacity of the **`StringBuffer`** is initially 35. Remember that the **`StringBuffer`** constructor that takes a **`String`** argument creates a **`StringBuffer`** object with an initial capacity that is the length of the **`String`** passed as an argument plus 16.

Line 20 expands the capacity of the **`StringBuffer`** to a minimum of 75 characters. Actually, if the original capacity is less than the argument, the method ensures a capacity that is the greater of the number specified as an argument or twice the original capacity plus 2. If the **`StringBuffer`**'s current capacity is more than the specified capacity, the **`StringBuffer`**'s capacity remains unchanged.

Line 23 uses method **`setLength`** to set the length of the **`StringBuffer`** to 10. If the specified length is less than the current number of characters in the **`StringBuffer`**,

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the characters are truncated to the specified length (i.e., the characters in the **StringBuffer** after the specified length are discarded). If the specified length is greater than the number of characters currently in the **StringBuffer**, null characters (characters with the numeric representation 0) are appended to the **StringBuffer** until the total number of characters in the **StringBuffer** is equal to the specified length.

10.16 StringBuffer Methods charAt, setCharAt, getChars and reverse

Class **StringBuffer** provides the **charAt**, **setCharAt**, **getChars** and **reverse** methods to manipulate the characters in a **StringBuffer**. Method **charAt** takes an integer argument and returns the character in the **StringBuffer** at that index. Method **setCharAt** takes an integer and a character argument and sets the character at the specified position to the character argument. The index specified in the **charAt** and **setCharAt** methods must be greater than or equal to 0 and less than the **StringBuffer** length; otherwise, a **StringIndexOutOfBoundsException** is generated.

Common Programming Error 10.5

*Attempting to access a character that is outside the bounds of a **StringBuffer** (i.e., an index less than 0 or an index greater than or equal to the **StringBuffer**'s length) results in a **StringIndexOutOfBoundsException**.*

Method **getChars** returns a character array containing a copy of the characters in the **StringBuffer**. This method takes four arguments—the starting index from which characters should be copied in the **StringBuffer**, the index one past the last character to be copied from the **StringBuffer**, the character array into which the characters are to be copied and the starting location in the character array where the first character should be placed. Method **reverse** reverses the contents of the **StringBuffer**. Each of these methods is demonstrated in Fig. 10.14.

```
1  // Fig. 10.14: StringBufferChars.java
2  // The charAt, setCharAt, getChars, and reverse methods
3  // of class StringBuffer.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringBufferChars {
9
10    // test StringBuffer character methods
11    public static void main( String args[] )
12    {
13       StringBuffer buffer = new StringBuffer( "hello there" );
14
15       String output = "buffer = " + buffer.toString() +
16          "\nCharacter at 0: " + buffer.charAt( 0 ) +
17          "\nCharacter at 4: " + buffer.charAt( 4 );
18
```

Fig. 10.14 **StringBuffer** class character manipulation methods.

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```
19          char charArray[] = new char[ buffer.length() ];
20          buffer.getChars( 0, buffer.length(), charArray, 0 );
21          output += "\n\nThe characters are: ";
22
23          for ( int count = 0; count < charArray.length; ++count )
24             output += charArray[ count ];
25
26          buffer.setCharAt( 0, 'H' );
27          buffer.setCharAt( 6, 'T' );
28          output += "\n\nbuf = " + buffer.toString();
29
30          buffer.reverse();
31          output += "\n\nbuf = " + buffer.toString();
32
33          JOptionPane.showMessageDialog( null, output,
34             "Demonstrating StringBuffer Character Methods",
35             JOptionPane.INFORMATION_MESSAGE );
36
37          System.exit( 0 );
38       }
39
40    }  // end class StringBufferChars
```

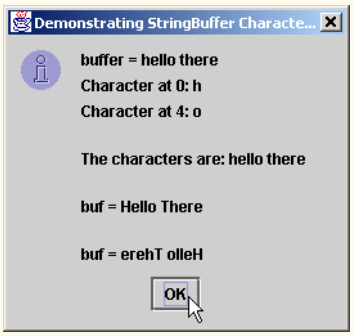

Fig. 10.14 **`StringBuffer`** class character manipulation methods.

10.17 `StringBuffer` append Methods

Class **`StringBuffer`** provides 10 overloaded **`append`** methods to allow various data-type values to be added to the end of a **`StringBuffer`**. Versions are provided for each of the primitive data types and for character arrays, **`String`**s and **`Object`**s. (Remember that method **`toString`** produces a **`String`** representation of any **`Object`**.) Each of the methods takes its argument, converts it to a **`String`** and appends it to the **`StringBuffer`**. The **`append`** methods are demonstrated in Fig. 10.15. [Note: Line 20 specifies the literal value **`2.5f`** as the initial value of a **`float`** variable. Normally, Java treats a floating-point literal value as type **`double`**. Appending the letter **`f`** to the literal **`2.5`** indicates to the compiler that **`2.5`** should be treated as type **`float`**. Without this indication the compiler generates a syntax error, because a **`double`** value cannot be assigned directly to a **`float`** variable in Java.]

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```
1  // Fig. 10.15: StringBufferAppend.java
2  // This program demonstrates the append
3  // methods of the StringBuffer class.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringBufferAppend {
9
10    // test StringBuffer append methods
11    public static void main( String args[] )
12    {
13       Object o = "hello";
14       String s = "good bye";
15       char charArray[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
16       boolean b = true;
17       char c = 'Z';
18       int i = 7;
19       long l = 10000000;
20       float f = 2.5f;
21       double d = 33.333;
22       StringBuffer buffer = new StringBuffer();
23
24       buffer.append( o );
25       buffer.append( "  " );
26
27       buffer.append( s );
28       buffer.append( "  " );
29       buffer.append( charArray );
30       buffer.append( "  " );
31       buffer.append( charArray, 0, 3 );
32       buffer.append( "  " );
33       buffer.append( b );
34       buffer.append( "  " );
35       buffer.append( c );
36       buffer.append( "  " );
37       buffer.append( i );
38       buffer.append( "  " );
39       buffer.append( l );
40       buffer.append( "  " );
41       buffer.append( f );
42       buffer.append( "  " );
43       buffer.append( d );
44
45       JOptionPane.showMessageDialog( null,
46          "buffer = " + buffer.toString(),
47          "Demonstrating StringBuffer append Methods",
48          JOptionPane.INFORMATION_MESSAGE );
49
50       System.exit( 0 );
51    }
52
53 }  // end StringBufferAppend
```

Fig. 10.15 **`StringBuffer`** class **`append`** methods (part 1 of 2).

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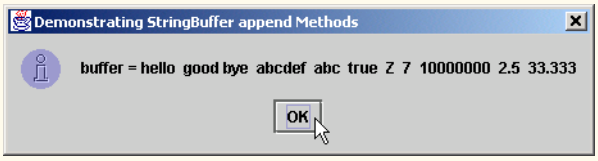

Fig. 10.15 **StringBuffer** class **append** methods (part 2 of 2).

Actually, **StringBuffer**s and the **append** methods are used by the compiler to implement the **+** and **+=** operators for concatenating **String**s. For example, assuming the following declarations:

```
String string1 = "hello";
String string2 = "BC"
int value = 22;
```

the statement

```
String s = string1 + string2 + value;
```

concatenates **"hello"**, **"BC"** and **22**. The concatenation is performed as follows:

```
new StringBuffer().append( "hello" ).append( "BC" ).append(
   22 ).toString();
```

First, Java creates a **StringBuffer**, then appends to the **StringBuffer** the **String** **"hello"**, the **String** **"BC"** and the integer **22**. Next, **StringBuffer**'s **toString** converts the **StringBuffer** to a **String** representation and the result is assigned to **String** **s**. The statement

```
s += "!";
```

is performed as follows:

```
s = new StringBuffer().append( s ).append( "!" ).toString()
```

First, Java creates a **StringBuffer**, then appends to the **StringBuffer** the current contents of **s** followed by **"!"**. Next, **StringBuffer**'s **toString** converts the **StringBuffer** to a **String** representation and the result is assigned to **s**

10.18 StringBuffer Insertion and Deletion Methods

Class **StringBuffer** provides nine overloaded **insert** methods to allow various data-type values to be inserted at any position in a **StringBuffer**. Versions are provided for each of the primitive data types and for character arrays, **String**s and **Object**s. (Remember that method **toString** produces a **String** representation of any **Object**.) Each of the methods takes its second argument, converts it to a **String** and inserts it preceding the index specified by the first argument. The index specified by the first argument must be greater than or equal to **0** and less than the length of the **StringBuffer**; otherwise, a **StringIndexOutOfBoundsException** is generated. Class **StringBuffer** also provides methods ***delete*** and ***deleteCharAt*** for deleting characters at

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any position in a **StringBuffer**. Method **delete** takes two arguments—the starting subscript and the subscript one past the end of the characters to delete. All characters beginning at the starting subscript up to, but not including the ending subscript are deleted. Method **deleteCharAt** takes one argument—the subscript of the character to delete. Invalid subscripts cause both methods to throw a **StringIndexOutOfBoundsException**. The **insert** and delete methods are demonstrated in Fig. 10.16.

```
1  // Fig. 10.16: StringBufferInsert.java
2  // This program demonstrates the insert and delete
3  // methods of class StringBuffer.
4
5  // Java extension packages
6  import javax.swing.*;
7
8  public class StringBufferInsert {
9
10    // test StringBuffer insert methods
11    public static void main( String args[] )
12    {
13       Object o = "hello";
14       String s = "good bye";
15       char charArray[] = { 'a', 'b', 'c', 'd', 'e', 'f' };
16       boolean b = true;
17       char c = 'K';
18       int i = 7;
19       long l = 10000000;
20       float f = 2.5f;
21       double d = 33.333;
22       StringBuffer buffer = new StringBuffer();
23
24       buffer.insert( 0, o );
25       buffer.insert( 0, "  " );
26       buffer.insert( 0, s );
27       buffer.insert( 0, "  " );
28       buffer.insert( 0, charArray );
29       buffer.insert( 0, "  " );
30       buffer.insert( 0, b );
31       buffer.insert( 0, "  " );
32       buffer.insert( 0, c );
33       buffer.insert( 0, "  " );
34       buffer.insert( 0, i );
35       buffer.insert( 0, "  " );
36       buffer.insert( 0, l );
37       buffer.insert( 0, "  " );
38       buffer.insert( 0, f );
39       buffer.insert( 0, "  " );
40       buffer.insert( 0, d );
41
42       String output =
43          "buffer after inserts:\n" + buffer.toString();
44
```

Fig. 10.16 **StringBuffer** class **insert** and **delete** methods (part 1 of 2).

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```
45          buffer.deleteCharAt( 10 );  // delete 5 in 2.5
46          buffer.delete( 2, 6 );      // delete .333 in 33.333
47
48          output +=
49             "\n\nbuffer after deletes:\n" + buffer.toString();
50
51          JOptionPane.showMessageDialog( null, output,
52             "Demonstrating StringBufferer Inserts and Deletes",
53             JOptionPane.INFORMATION_MESSAGE );
54
55          System.exit( 0 );
56       }
57
58    }  // end class StringBufferInsert
```

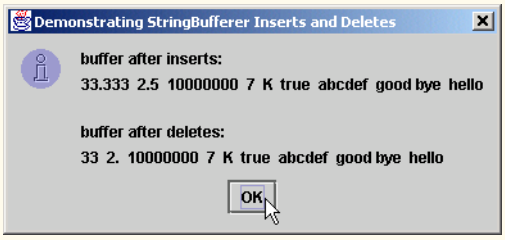

Fig. 10.16 **`StringBuffer`** class **`insert`** and **`delete`** methods (part 2 of 2).

10.19 `Character` Class Examples

Java provides a number of classes that enable primitive variables to be treated as objects. The classes are **`Boolean`**, **`Character`**, **`Double`**, **`Float`**, **`Byte`**, **`Short`**, **`Integer`** and **`Long`**. These classes (except **`Boolean`** and **`Character`**) are derived from **`Number`**. These eight classes are known as *type wrappers*, and they are part of the **`java.lang`** package. Objects of these classes can be used anywhere in a program that an **`Object`** or a **`Number`** is expected. In this section, we present class **`Character`**—the type-wrapper class for characters.

Most **`Character`** class methods are **`static`**, take at least a character argument and perform either a test or a manipulation of the character. This class also contains a constructor that receives a **`char`** argument to initialize a **`Character`** object and several non-**`static`** methods. Most of the methods of class **`Character`** are presented in the next three examples. For more information on class **`Character`** (and all the wrapper classes), see the **`java.lang`** package in the Java API documentation.

Figure 10.17 demonstrates some **`static`** methods that test characters to determine whether they are a specific character type and the **`static`** methods that perform case conversions on characters. Each method is used in method **`buildOutput`** of class **`StaticCharMethods`**. You can enter any character and apply the preceding methods to the character. Note the use of inner classes for the event handling as demonstrated in Chapter 9.

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Line 63 uses **`Character`** method **`isDefined`** to determine if character **`c`** is defined in the Unicode character set. If so, the method returns **`true`**; otherwise, it returns **`false`**.

```
1  // Fig. 10.17: StaticCharMethods.java
2  // Demonstrates the static character testing methods
3  // and case conversion methods of class Character
4  // from the java.lang package.
5
6  // Java core packages
7  import java.awt.*;
8  import java.awt.event.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class StaticCharMethods extends JFrame {
14    private char c;
15    private JLabel promptLabel;
16    private JTextField inputField;
17    private JTextArea outputArea;
18
19    // set up GUI
20    public StaticCharMethods()
21    {
22       super( "Static Character Methods" );
23
24       Container container = getContentPane();
25       container.setLayout( new FlowLayout() );
26
27       promptLabel =
28          new JLabel( "Enter a character and press Enter" );
29       container.add( promptLabel );
30
31       inputField = new JTextField( 5 );
32
33       inputField.addActionListener(
34
35          // anonymous inner class
36          new ActionListener() {
37
38             // handle text field event
39             public void actionPerformed( ActionEvent event )
40             {
41                String s = event.getActionCommand();
42                c = s.charAt( 0 );
43                buildOutput();
44             }
45
46          }  // end anonymous inner class
47
48       ); // end call to addActionListener
```

Fig. 10.17 **`static`** character testing methods and case conversion methods of class **`Character`** (part 1 of 3).

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```
49
50          container.add( inputField );
51
52          outputArea = new JTextArea( 10, 20 );
53          container.add( outputArea );
54
55          setSize( 300, 250 );  // set the window size
56          show();               // show the window
57       }
58
59       // display character info in outputArea
60       public void buildOutput()
61       {
62          outputArea.setText(
63             "is defined: " + Character.isDefined( c ) +
64             "\nis digit: " + Character.isDigit( c ) +
65             "\nis Java letter: " +
66             Character.isJavaIdentifierStart( c ) +
67             "\nis Java letter or digit: " +
68             Character.isJavaIdentifierPart( c ) +
69             "\nis letter: " + Character.isLetter( c ) +
70             "\nis letter or digit: " +
71             Character.isLetterOrDigit( c ) +
72             "\nis lower case: " + Character.isLowerCase( c ) +
73             "\nis upper case: " + Character.isUpperCase( c ) +
74             "\nto upper case: " + Character.toUpperCase( c ) +
75             "\nto lower case: " + Character.toLowerCase( c ) );
76       }
77
78       // execute application
79       public static void main( String args[] )
80       {
81          StaticCharMethods application = new StaticCharMethods();
82
83          application.addWindowListener(
84
85             // anonymous inner class
86             new WindowAdapter() {
87
88                // handle event when user closes window
89                public void windowClosing( WindowEvent windowEvent )
90                {
91                   System.exit( 0 );
92                }
93
94             }  // end anonymous inner class
95
96          ); // end call to addWindowListener
97
98       }  // end method main
99
100   }  // end class StaticCharMethods
```

Fig. 10.17 **`static`** character testing methods and case conversion methods of class **`Character`** (part 2 of 3).

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Fig. 10.17 **`static`** character testing methods and case conversion methods of class **`Character`** (part 3 of 3).

Line 64 uses **`Character`** method **`isDigit`** to determine whether character **`c`** is a defined Unicode digit. If so, the method returns **`true`**; otherwise, it returns **`false`**.

Line 66 uses **`Character`** method **`isJavaIdentifierStart`** to determine whether **`c`** is a character that can be used as the first character of an identifier in Java—i.e., a letter, an underscore (_) or a dollar sign (**`$`**). If so, the method returns **`true`**; otherwise, it returns **`false`**. Line 68 uses method **`Character`** method **`isJavaIdentifierPart`** to determine whether character **`c`** is a character that can be used in an identifier in Java—i.e., a digit, a letter, an underscore (_) or a dollar sign (**`$`**). If so, the method returns **`true`**; otherwise, it returns **`false`**.

Line 69 uses method **`Character`** method **`isLetter`** to determine whether character **`c`** is a letter. If so, the method returns **`true`**; otherwise, it returns **`false`**. Line 71 uses method **`Character`** method **`isLetterOrDigit`** to determine whether character **`c`** is a letter or a digit. If so, the method returns **`true`**; otherwise, it returns **`false`**.

Line 72 uses method **`Character`** method **`isLowerCase`** to determine whether character **`c`** is a lowercase letter. If so, the method returns **`true`**; otherwise, it returns **`false`**. Line 73 uses method **`Character`** method **`isUpperCase`** to determine whether character **`c`** is an uppercase letter. If so, the method returns **`true`**; otherwise, it returns **`false`**.

Line 74 uses method **`Character`** method **`toUpperCase`** to convert the character **`c`** to its uppercase equivalent. The method returns the converted character if the character has an uppercase equivalent; otherwise, the method returns its original argument. Line 75 uses method **`Character`** method **`toLowerCase`** to convert the character **`c`** to its lowercase

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equivalent. The method returns the converted character if the character has a lowercase equivalent; otherwise, the method returns its original argument.

Figure 10.18 demonstrates **static Character** methods **digit** and **forDigit**, which perform conversions between characters and digits in different number systems. Common number systems include decimal (base 10), octal (base 8), hexadecimal (base 16) and binary (base 2). The base of a number is also known as its *radix*. For more information on conversions between number systems, see Appendix E.

Line 52 uses method **forDigit** to convert the integer **digit** into a character in the number system specified by the integer **radix** (also known as the base of the number). For example, the integer **13** in base 16 (the **radix**) has the character value **'d'**. Note that the lowercase and uppercase letters are equivalent in number systems.

Line 77 uses method **digit** to convert the character **c** into an integer in the number system specified by the integer **radix** (i.e., the base of the number). For example, the character **'A'** in base 16 (the **radix**) has the integer value 10.

```
1  // Fig. 10.18: StaticCharMethods2.java
2  // Demonstrates the static character conversion methods
3  // of class Character from the java.lang package.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class StaticCharMethods2 extends JFrame {
13    private char c;
14    private int digit, radix;
15    private JLabel prompt1, prompt2;
16    private JTextField input, radixField;
17    private JButton toChar, toInt;
18
19    public StaticCharMethods2()
20    {
21       super( "Character Conversion Methods" );
22
23       // set up GUI and event handling
24       Container container = getContentPane();
25       container.setLayout( new FlowLayout() );
26
27       prompt1 = new JLabel( "Enter a digit or character " );
28       input = new JTextField( 5 );
29       container.add( prompt1 );
30       container.add( input );
31
32       prompt2 = new JLabel( "Enter a radix " );
33       radixField = new JTextField( 5 );
34       container.add( prompt2 );
35       container.add( radixField );
```

Fig. 10.18 **Character** class **static** conversion methods (part 1 of 3).

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```
36
37          toChar = new JButton( "Convert digit to character" );
38
39          toChar.addActionListener(
40
41             // anonymous inner class
42             new ActionListener() {
43
44                // handle toChar JButton event
45                public void actionPerformed( ActionEvent actionEvent )
46                {
47                   digit = Integer.parseInt( input.getText() );
48                   radix =
49                      Integer.parseInt( radixField.getText() );
50                   JOptionPane.showMessageDialog( null,
51                      "Convert digit to character: " +
52                      Character.forDigit( digit, radix ) );
53                }
54
55             }  // end anonymous inner class
56
57          ); // end call to addActionListener
58
59          container.add( toChar );
60
61          toInt = new JButton( "Convert character to digit" );
62
63          toInt.addActionListener(
64
65             // anonymous inner class
66             new ActionListener() {
67
68                // handle toInt JButton event
69                public void actionPerformed( ActionEvent actionEvent )
70                {
71                   String s = input.getText();
72                   c = s.charAt( 0 );
73                   radix =
74                      Integer.parseInt( radixField.getText() );
75                   JOptionPane.showMessageDialog( null,
76                      "Convert character to digit: " +
77                      Character.digit( c, radix ) );
78                }
79
80             }  // end anonymous inner class
81
82          ); // end call to addActionListener
83
84          container.add( toInt );
85
86          setSize( 275, 150 );  // set the window size
87          show();               // show the window
88       }
```

Fig. 10.18 **`Character`** class **`static`** conversion methods (part 2 of 3).

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```
89
90       // execute application
91       public static void main( String args[] )
92       {
93          StaticCharMethods2 application = new StaticCharMethods2();
94
95          application.addWindowListener(
96
97             // anonymous inner class
98             new WindowAdapter() {
99
100               // handle event when user closes window
101               public void windowClosing( WindowEvent windowEvent )
102               {
103                  System.exit( 0 );
104               }
105
106            }  // end anonymous inner class
107
108         ); // end call to addWindowListener
109
110      }  // end method main
111
112   }  // end class StaticCharMethods2
```

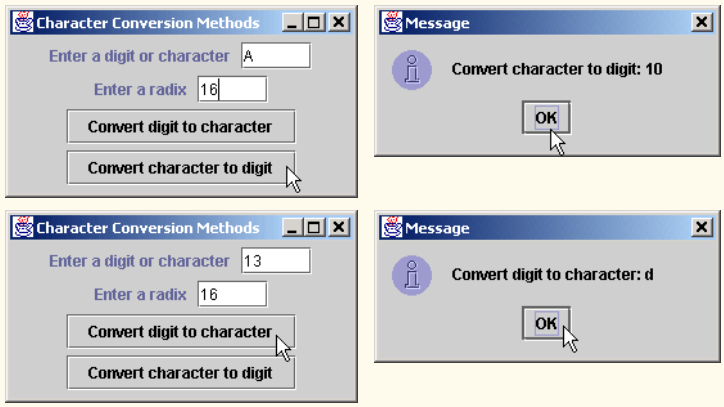

Fig. 10.18 **Character** class **static** conversion methods (part 3 of 3).

The program in Fig. 10.19 demonstrates the non**static** methods of class **Character**—the constructor, **charValue**, **toString**, **hashCode** and **equals**.

```
1  // Fig. 10.19: OtherCharMethods.java
2  // Demonstrate the non-static methods of class
3  // Character from the java.lang package.
4
5  // Java extension packages
6  import javax.swing.*;
```

Fig. 10.19 Non-**static** methods of class **Character** (part 1 of 2).

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```
 7
 8  public class OtherCharMethods {
 9
10     // test non-static Character methods
11     public static void main( String args[] )
12     {
13        Character c1, c2;
14
15        c1 = new Character( 'A' );
16        c2 = new Character( 'a' );
17
18        String output = "c1 = " + c1.charValue() +
19           "\nc2 = " + c2.toString() +
20           "\n\nhash code for c1 = " + c1.hashCode() +
21           "\nhash code for c2 = " + c2.hashCode();
22
23        if ( c1.equals( c2 ) )
24           output += "\n\nc1 and c2 are equal";
25        else
26           output += "\n\nc1 and c2 are not equal";
27
28        JOptionPane.showMessageDialog( null, output,
29           "Demonstrating Non-Static Character Methods",
30           JOptionPane.INFORMATION_MESSAGE );
31
32        System.exit( 0 );
33     }
34
35  }  // end class OtherCharMethods
```

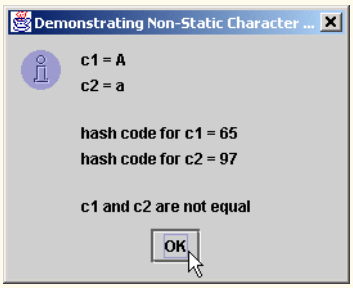

Fig. 10.19 Non-**static** methods of class **Character** (part 2 of 2).

Lines 15–16 instantiate two **Character** objects and pass character literals to the constructor to initialize those objects.

Line 18 uses **Character** method **charValue** to return the **char** value stored in **Character** object **c1**. Line 19 returns a **String** representation of **Character** object **c2** using method **toString**.

Lines 20–21perform **hashCode** calculations on the **Character** objects **c1** and **c2**, respectively. Remember that hash code values are used to store objects in hash tables for fast lookup capabilities (see Chapter 20).

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The condition in the **if** structure on line 23 uses method **equals** to determine whether the object **c1** has the same contents as the object **c2** (i.e., the characters inside each object are equal).

10.20 Class StringTokenizer

When you read a sentence, your mind breaks the sentence into individual words and punctuation, or *tokens,* each of which conveys meaning to you. Compilers also perform tokenization. They break up statements into individual pieces like keywords, identifiers, operators and other elements of a programming language. In this section, we study Java's **StringTokenizer** class (from package **java.util**), which breaks a string into its component tokens. Tokens are separated from one another by delimiters, typically white-space characters such as blank, tab, newline and carriage return. Other characters can also be used as delimiters to separate tokens. The program in Fig. 10.20 demonstrates class **StringTokenizer**. The window for class **TokenTest** displays a **JTextField** where the user types a sentence to tokenize. Output in this program is displayed in a **JTextArea**.

When the user presses the *Enter* key in the **JTextField**, method **actionPerformed** (lines 37–49) is invoked. Lines 39–40 assign **String** reference **stringToTokenize** the value in the text in the **JTextField** returned by calling **event.getActionCommand()**. Next, lines 41–42 create an instance of class **StringTokenizer**. This **StringTokenizer** constructor takes a **String** argument and creates a **StringTokenizer** for **stringToTokenize** that will use the default delimiter string **" \n\t\r"** consisting of a space, a newline, a tab and a carriage return for tokenization. There are two other constructors for class **StringTokenizer**. In the version that takes two **String** arguments, the second **String** is the delimiter **String**. In the version that takes three arguments, the second **String** is the delimiter **String** and the third argument (a **boolean**) determines whether the delimiters are also returned as tokens (only if the argument is **true**). This is useful if you need to know what the delimiters are.

```
1  // Fig. 10.20: TokenTest.java
2  // Testing the StringTokenizer class of the java.util package
3
4  // Java core packages
5  import java.util.*;
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class TokenTest extends JFrame {
13    private JLabel promptLabel;
14    private JTextField inputField;
15    private JTextArea outputArea;
16
```

Fig. 10.20 Tokenizing strings with a **StringTokenizer** object (part 1 of 3).

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```
17     // set up GUI and event handling
18     public TokenTest()
19     {
20        super( "Testing Class StringTokenizer" );
21
22        Container container = getContentPane();
23        container.setLayout( new FlowLayout() );
24
25        promptLabel =
26           new JLabel( "Enter a sentence and press Enter" );
27        container.add( promptLabel );
28
29        inputField = new JTextField( 20 );
30
31        inputField.addActionListener(
32
33           // anonymous inner class
34           new ActionListener() {
35
36              // handle text field event
37              public void actionPerformed( ActionEvent event )
38              {
39                 String stringToTokenize =
40                    event.getActionCommand();
41                 StringTokenizer tokens =
42                    new StringTokenizer( stringToTokenize );
43
44                 outputArea.setText( "Number of elements: " +
45                    tokens.countTokens() + "\nThe tokens are:\n" );
46
47                 while ( tokens.hasMoreTokens() )
48                    outputArea.append( tokens.nextToken() + "\n" );
49              }
50
51           }  // end anonymous inner class
52
53        ); // end call to addActionListener
54
55        container.add( inputField );
56
57        outputArea = new JTextArea( 10, 20 );
58        outputArea.setEditable( false );
59        container.add( new JScrollPane( outputArea ) );
60
61        setSize( 275, 260 );  // set the window size
62        show();               // show the window
63     }
64
65     // execute application
66     public static void main( String args[] )
67     {
68        TokenTest application = new TokenTest();
69
```

Fig. 10.20 Tokenizing strings with a **`StringTokenizer`** object (part 2 of 3).

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```
70         application.addWindowListener(
71
72            // anonymous inner class
73            new WindowAdapter() {
74
75               // handle event when user closes window
76               public void windowClosing( WindowEvent windowEvent )
77               {
78                  System.exit( 0 );
79               }
80
81            }  // end anonymous inner class
82
83         ); // end call to addWindowListener
84
85      }  // end method main
86
87   }  // end class TokenTest
```

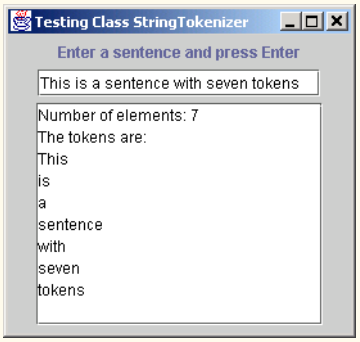

Fig. 10.20 Tokenizing strings with a **`StringTokenizer`** object (part 3 of 3).

The statement at lines 44–45 uses the **`StringTokenizer`** method **`countTokens`** to determine the number of tokens in the **`String`** to be tokenized.

The condition in the **`while`** structure at lines 47–48 **`StringTokenizer`** method **`hasMoreTokens`** to determine whether there are more tokens in the **`String`** being tokenized. If so, the **`append`** method is invoked for the **`JTextArea outputArea`** to append the next token to the **`String`** in the **`JTextArea`**. The next token is obtained with a call to **`StringTokenizer`** method **`nextToken`** that returns a **`String`**. The token is output followed by a newline character, so subsequent tokens appear on separate lines.

If you would like to change the delimiter **`String`** while tokenizing a **`String`**, you may do so by specifying a new delimiter string in a **`nextToken`** call as follows:

```
tokens.nextToken( newDelimiterString );
```

This feature is not demonstrated in the program.

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10.21 Card Shuffling and Dealing Simulation

In this section, we use random number generation to develop a card shuffling and dealing simulation program. This program can then be used to implement programs that play specific card games.

We develop application **DeckOfCards** (Fig. 10.21), which creates a deck of 52 playing cards using **Card** objects, then enables the user to deal each card by clicking on a "**Deal card**" button. Each card dealt is displayed in a **JTextField**. The user can also shuffle the deck at any time by clicking on a "**Shuffle cards**" button.

```
1  // Fig. 10.21: DeckOfCards.java
2  // Card shuffling and dealing program
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class DeckOfCards extends JFrame {
12    private Card deck[];
13    private int currentCard;
14    private JButton dealButton, shuffleButton;
15    private JTextField displayField;
16    private JLabel statusLabel;
17
18    // set up deck of cards and GUI
19    public DeckOfCards()
20    {
21       super( "Card Dealing Program" );
22
23       String faces[] = { "Ace", "Deuce", "Three", "Four",
24          "Five", "Six", "Seven", "Eight", "Nine", "Ten",
25          "Jack", "Queen", "King" };
26       String suits[] =
27          { "Hearts", "Diamonds", "Clubs", "Spades" };
28
29       deck = new Card[ 52 ];
30       currentCard = -1;
31
32       // populate deck with Card objects
33       for ( int count = 0; count < deck.length; count++ )
34          deck[ count ] = new Card( faces[ count % 13 ],
35             suits[ count / 13 ] );
36
37       // set up GUI and event handling
38       Container container = getContentPane();
39       container.setLayout( new FlowLayout() );
40
41       dealButton = new JButton( "Deal card" );
```

Fig. 10.21 Card dealing program (part 1 of 4).

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```
42          dealButton.addActionListener(
43
44             // anonymous inner class
45             new ActionListener() {
46
47                // deal one card
48                public void actionPerformed( ActionEvent actionEvent )
49                {
50                   Card dealt = dealCard();
51
52                   if ( dealt != null ) {
53                      displayField.setText( dealt.toString() );
54                      statusLabel.setText( "Card #: " + currentCard );
55                   }
56                   else {
57                      displayField.setText(
58                         "NO MORE CARDS TO DEAL" );
59                      statusLabel.setText(
60                         "Shuffle cards to continue" );
61                   }
62                }
63
64             }  // end anonymous inner class
65
66          ); // end call to addActionListener
67
68          container.add( dealButton );
69
70          shuffleButton = new JButton( "Shuffle cards" );
71          shuffleButton.addActionListener(
72
73             // anonymous inner class
74             new ActionListener() {
75
76                // shuffle deck
77                public void actionPerformed( ActionEvent actionEvent )
78                {
79                   displayField.setText( "SHUFFLING ..." );
80                   shuffle();
81                   displayField.setText( "DECK IS SHUFFLED" );
82                }
83
84             }  // end anonymous inner class
85
86          ); // end call to addActionListener
87
88          container.add( shuffleButton );
89
90          displayField = new JTextField( 20 );
91          displayField.setEditable( false );
92          container.add( displayField );
93
94          statusLabel = new JLabel();
```

Fig. 10.21 Card dealing program (part 2 of 4).

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```
95          container.add( statusLabel );
96
97          setSize( 275, 120 );   // set window size
98          show();                // show window
99       }
100
101      // shuffle deck of cards with one-pass algorithm
102      public void shuffle()
103      {
104         currentCard = -1;
105
106         // for each card, pick another random card and swap them
107         for ( int first = 0; first < deck.length; first++ ) {
108            int second =  ( int ) ( Math.random() * 52 );
109            Card temp = deck[ first ];
110            deck[ first ] = deck[ second ];
111            deck[ second ] = temp;
112         }
113
114         dealButton.setEnabled( true );
115      }
116
117      // deal one card
118      public Card dealCard()
119      {
120         if ( ++currentCard < deck.length )
121            return deck[ currentCard ];
122         else {
123            dealButton.setEnabled( false );
124            return null;
125         }
126      }
127
128      // execute application
129      public static void main( String args[] )
130      {
131         DeckOfCards app = new DeckOfCards();
132
133         app.addWindowListener(
134
135            // anonymous inner class
136            new WindowAdapter() {
137
138               // terminate application when user closes window
139               public void windowClosing( WindowEvent windowEvent )
140               {
141                  System.exit( 0 );
142               }
143
144            }  // end anonymous inner class
145
146         ); // end call to addWindowListener
147
```

Fig. 10.21 Card dealing program (part 3 of 4).

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```
148     }  // end method main
149
150  }  // end class DeckOfCards
151
152  // class to represent a card
153  class Card {
154     private String face;
155     private String suit;
156
157     // constructor to initialize a card
158     public Card( String cardFace, String cardSuit )
159     {
160        face = cardFace;
161        suit = cardSuit;
162     }
163
164     // return String represenation of Card
165     public String toString()
166     {
167        return face + " of " + suit;
168     }
169
170  }  // end class Card
```

Fig. 10.21 Card dealing program (part 4 of 4).

Class **Card** (lines 153–170) contains two **String** instance variables—**face** and **suit**—that are used to store references to the face name and suit name for a specific **Card**. The constructor for the class receives two **String**s that it uses to initialize **face** and **suit**. Method **toString** is provided to create a **String** consisting of the **face** of the card, the string **" of "** and the **suit** of the card.

Class **DeckOfCards** (lines 11–150) consists of an array **deck** of 52 **Card**s, an integer **currentCard** representing the most recently dealt card in the deck array (–1 if no cards have been dealt yet) and the GUI components used to manipulate the deck of cards. The constructor method of the application instantiates the **deck** array (line 29) and uses the **for** structure at lines 33–35 to fill the **deck** array with **Card**s. Note that each **Card** is instantiated and initialized with two **String**s—one from the **faces** array (**String**s **"Ace"** through **"King"**) and one from the **suits** array (**"Hearts"**, **"Diamonds"**, **"Clubs"** and **"Spades"**). The calculation **count % 13** always results in a value from 0 to 12 (the

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thirteen subscripts of the **faces** array), and the calculation **count / 13** always results in a value from 0 to 3 (the four subscripts in the **suits** array). When the **deck** array is initialized, it contains the cards with faces ace through king in order for each suit.

When the user clicks the **Deal card** button, method **actionPerformed** at lines 48–62 invokes method **dealCard** (defined at lines 118–126) to get the next card in the array. If the **deck** is not empty, a **Card** object reference is returned; otherwise, **null** is returned. If the reference is not **null**, lines 53–54 display the **Card** in the **JTextField displayField** and display the card number in the **JLabel statusLabel**. If the reference returned by **dealCard** was **null**, the **String** "**NO MORE CARDS TO DEAL**" is displayed in the **JTextField** and the **String** "**Shuffle cards to continue**" is displayed in the **JLabel**.

When the user clicks the **Shuffle cards** button, its **actionPerformed** method at lines 77–82 invokes method **shuffle** (defined on lines 102–115) to shuffle the cards. The method loops through all 52 cards (array subscripts 0 to 51). For each card, a number between 0 and 51 is picked randomly. Next, the current **Card** object and the randomly selected **Card** object are swapped in the array. A total of only 52 swaps are made in a single pass of the entire array, and the array of **Card** objects is shuffled! When the shuffling is complete, the **String** "**DECK IS SHUFFLED**" is displayed in the **JTextField**.

Notice the use of method **setEnabled** at lines 114 and 123 to activate and deactivate the **dealButton**. Method **setEnabled** can be used on many GUI components. When it is called with a **false** argument, the GUI component for which it is called is disabled so the user cannot interact with it. To reactivate the button, method **setEnabled** is called with a **true** argument.

10.22 (Optional Case Study) Thinking About Objects: Event Handling

Objects do not ordinarily perform their operations spontaneously. Rather, a specific operation is normally invoked when a sending object (a *client object*) sends a *message* to a receiving object (a *server object*) requesting that the receiving object perform that specific operation. In earlier sections, we mentioned that objects interact by sending and receiving messages. We began to model the behavior of our elevator system by using statechart and activity diagrams in Section 5.11 and collaboration diagrams in Section 7.10. In this section, we discuss how the objects of the elevator system interact.

Events

In Fig. 7.24, we presented an example of a person pressing a button by sending a **pressButton** message to the button—specifically, the **Person** object called method **pressButton** of the **Button** object. This message describes an action that is currently happening; in other words, the **Person** presses a **Button**. In general, the message name structure is a verb preceding a noun—e.g., the name of the **pressButton** message consists of the verb "press" followed by the noun "button."

An *event* is a message that notifies an object of an action that has already happened. For example, in this section, we modify our simulation so the **Elevator** sends an **elevatorArrived** event to the **Elevator**'s **Door** when the **Elevator** arrives at a **Floor**. In Section 7.10, the **Elevator** opens this **Door** directly by sending an **openDoor** message. Listening for an **elevatorArrived** event allows the **Door** to determine the actions

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to take when the **Elevator** has arrived, such as notifying the **Person** that the **Door** has opened. This reinforces the OOD principle of encapsulation and models the real world more closely. In reality, the door—not the elevator—"notifies" a person of a door's opening.

Notice that the event-naming structure is the inverse of the first type of message's naming structure. By convention, the event name consists of the noun preceding the verb. For instance, the **elevatorArrived** event name consists of the noun "elevator" preceding the verb "arrived."

In our simulation, we create a superclass called **ElevatorModelEvent** (Fig. 10.23) that represents an event in our model. **ElevatorModelEvent** contains a **Location** reference (line 11) that represents the location where the event was generated and an **Object** reference (line 14) to the source of the event. In our simulation, objects use instances of **ElevatorModelEvent** to send events to other objects. When an object receives an event, that object may use method **getLocation** (lines 31–34) and method **getSource** (lines 43–46) to determine the event's location and origin.

```
1  // ElevatorModelEvent.java
2  // Basic event packet holding Location object
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class ElevatorModelEvent {
9
10    // Location that generated ElevatorModelEvent
11    private Location location;
12
13    // source of generated ElevatorModelEvent
14    private Object source;
15
16    // ElevatorModelEvent constructor sets Location
17    public ElevatorModelEvent( Object source,
18       Location location )
19    {
20       setSource( source );
21       setLocation( location );
22    }
23
24    // set ElevatorModelEvent Location
25    public void setLocation( Location eventLocation )
26    {
27       location = eventLocation;
28    }
29
30    // get ElevatorModelEvent Location
31    public Location getLocation()
32    {
33       return location;
34    }
```

Fig. 10.23 Class **ElevatorModelEvent** is the superclass for all other event classes in our model (part 1 of 2).

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```
35
36      // set ElevatorModelEvent source
37      private void setSource( Object eventSource )
38      {
39         source = eventSource;
40      }
41
42      // get ElevatorModelEvent source
43      public Object getSource()
44      {
45         return source;
46      }
47   }
```

Fig. 10.23 Class **ElevatorModelEvent** is the superclass for all other event classes in our model (part 2 of 2).

For example, a **Door** may send an **ElevatorModelEvent** to a **Person** when opening or closing, and the **Elevator** may send an **ElevatorModelEvent** informing a person of a departure or arrival. Having different objects send the same event type to describe different actions could be confusing. To eliminate ambiguity as we discuss what events are sent by objects, we create several **ElevatorModelEvent** subclasses in Fig. 10.24, so we will have an easier time associating each event with its sender. According to Fig. 10.24, classes **BellEvent**, **PersonMoveEvent**, **LightEvent**, **ButtonEvent**, **ElevatorMoveEvent** and **DoorEvent** are subclasses of class **ElevatorModelEvent**. Using these event subclasses, a **Door** sends a different event (a **DoorEvent**) than does a **Button** (which sends a **ButtonEvent**). Figure 10.25 displays the triggering actions of the subclass events. Note that all actions in Fig. 10.25 appear in the form "noun" + "verb".

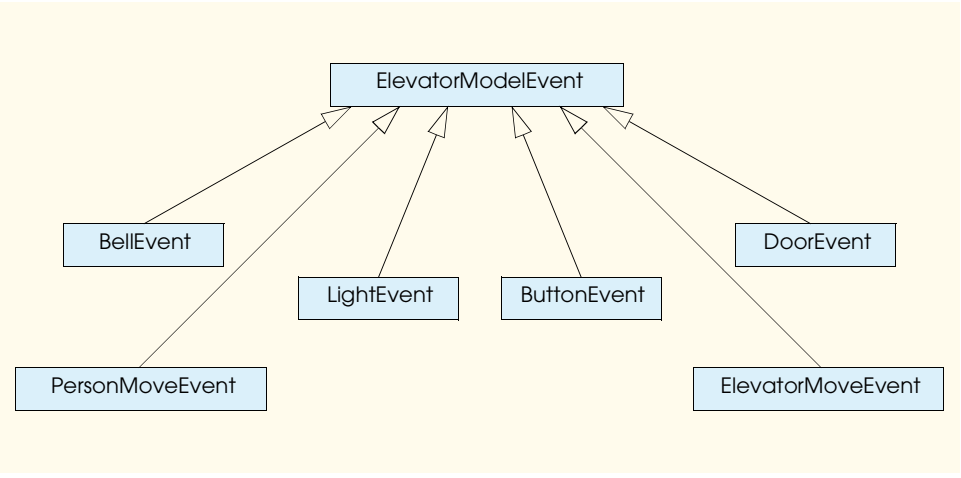

Fig. 10.24 Class diagram that models the generalization between **ElevatorModelEvent** and its subclasses.

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Event	Sent when (triggering action)	Sent by object of class
BellEvent	the **Bell** has rung	**Bell**
ButtonEvent	a **Button** has been pressed	**Button**
	a **Button** has been reset	**Button**
DoorEvent	a **Door** has opened	**Door**
	a **Door** has closed	**Door**
LightEvent	a **Light** has turned on	**Light**
	a **Light** has turned off	
PersonMoveEvent	a **Person** has been created	**Person**
	a **Person** has arrived at the **Elevator**	
	a **Person** has entered the **Elevator**	
	a **Person** has exited the **Elevator**	
	a **Person** has pressed a **Button**	
	a **Person** has exited the simulation	
ElevatorMoveEvent	the **Elevator** has arrived at a **Floor**	**Elevator**
	the **Elevator** has departed from a **Floor**	

Fig. 10.25 Triggering actions of the **ElevatorModelEvent** subclass events.

Event Handling

The concept of event handling in Java is similar to the concept of a *collaboration* described in Section 7.10. Event handling consists of an object of one class sending a particular message (which Java calls an *event*) to objects of other classes *listening for that type of message*.[1] The difference is that the objects receiving the message must *register* to receive the message; therefore, event handling describes *how* an object sends an event to other objects "listening" for that type of event—these objects are called *event listeners*. To send an event, the sending object invokes a particular method of the receiving object while passing the desired event object as a parameter. In our simulation, this event object belongs to a class that extends **ElevatorModelEvent**.

We presented a collaboration diagram in Fig. 7.25 showing interactions of two **Person** objects—**waitingPassenger** and **ridingPassenger**—as they enter and exit the **Elevator**. Figure 10.26 shows a modified diagram that incorporates event handling. There are three differences between the diagrams. First, we provide *notes*—explanatory remarks about some of the graphics in the diagram. The UML represents notes as rectangles with the upper right corners "folded over." Notes in the UML are similar to *comments* in Java. A dotted line associates a note with any component of the UML (object, class, arrow, etc.). In this diagram, the **<<parameter>>** notation specifies that the note contains the parameters of a given message: all **doorOpened** events pass a **DoorEvent** object as a parameter; all **elevatorArrived** events pass an **ElevatorMoveEvent** object; all **openDoor** messages pass a **Location** object.

1. Technically, one object sends a notification of an event—or some triggering action—to another object. However, Java parlance refers to sending this notification as "sending an event."

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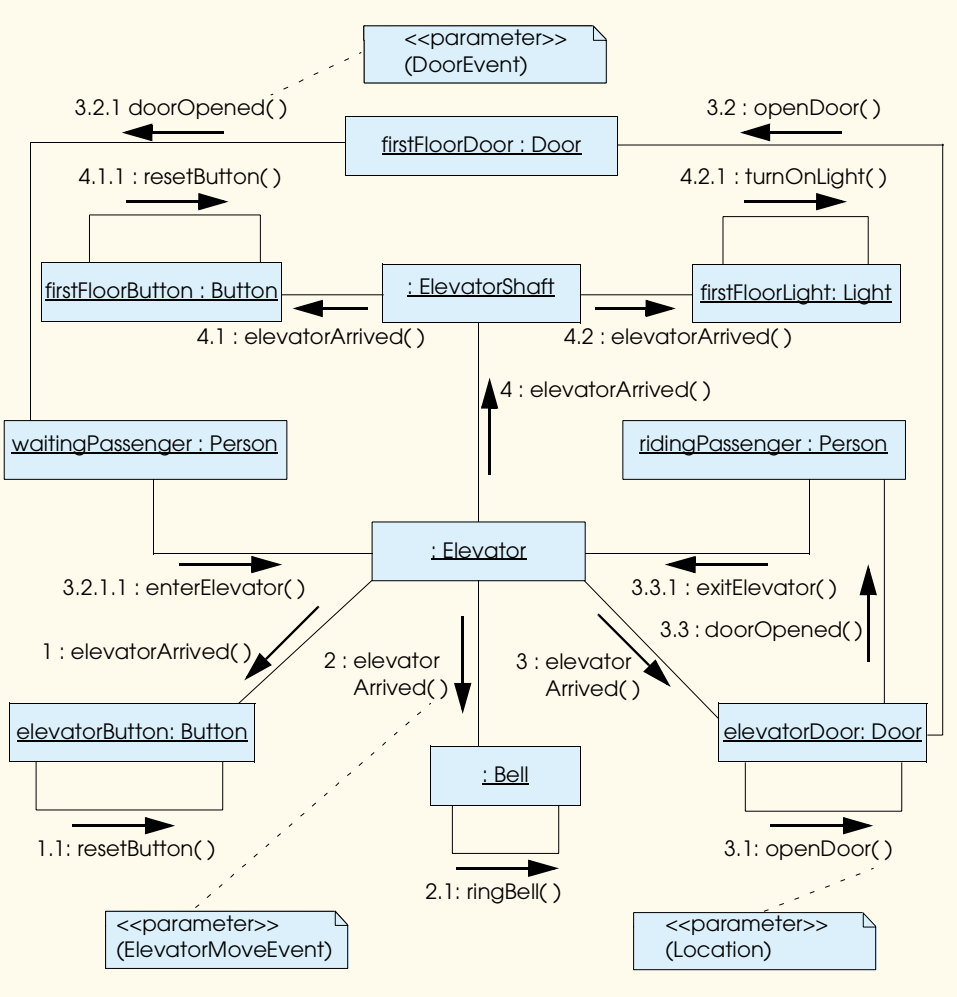

Fig. 10.26 Modified collaboration diagram for passengers entering and exiting the **`Elevator`** on the first **`Floor`**.

The second difference between the diagrams is that the interactions of Fig. 10.26 occur on the first **`Floor`**. This allows us to name all **`Button`** and **`Door`** objects (**`firstFloorDoor`** and **`firstFloorButton`**) to eliminate ambiguity, because the **`Button`** and **`Door`** classes each have three objects in our simulation. The interactions that occur on the second **`Floor`** are identical to the ones that occur on the first **`Floor`**.

The most substantial difference between Fig. 10.26 and Fig. 7.25 is that the **`Elevator`** *informs* objects (via an event) of an action *that has already happened*—the **`Elevator`** *has arrived*. The objects that receive the event then perform some action in response to the type of message they receive.

According to messages **`1`**, **`2`**, **`3`** and **`4`**, the **`Elevator`** performs only one action—it sends **`elevatorArrived`** events to objects interested in receiving those events. Specif-

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ically, the **Elevator** object sends an **ElevatorMoveEvent** using the receiving object's **elevatorArrived** method. Figure 10.26 begins with the **Elevator** sending an **elevatorArrived** event to the **elevatorButton**. The **elevatorButton** then *resets itself* (message **1.1**). The **Elevator** then sends an **elevatorArrived** event to the **Bell** (message **2**), and the **Bell** invokes its **ringBell** method, accordingly (i.e., the **Bell** object sends *itself* a **ringBell** message in message **2.1**).

The **Elevator** sends an **elevatorArrived** message to the **elevatorDoor** (message **3**). The **elevatorDoor** then opens itself by invoking its **openDoor** method (message **3.1**). At this point, the **elevatorDoor** is open but has not informed the **ridingPassenger** of opening. Before informing the **ridingPassenger**, the **elevatorDoor** opens the **firstFloorDoor** by sending an **openDoor** message to the **firstFloorDoor** (message **3.2**)—this guarantees that the **ridingPassenger** will not exit before the **firstFloorDoor** opens. The **firstFloorDoor** then informs the **waitingPassenger** that the **firstFloorDoor** has opened (message **3.2.1**), and the **waitingPassenger** enters the **Elevator** (message **3.2.1.1**). All messages nested in **3.2** have been passed, so the **elevatorDoor** may inform the **ridingPassenger** that **elevatorDoor** has opened by invoking method **doorOpened** of the **ridingPassenger** (message **3.3**). The **ridingPassenger** responds by exiting the **Elevator** (message **3.3.1**).[2]

Lastly, the **Elevator** informs the **ElevatorShaft** of the arrival (message **4**). The **ElevatorShaft** then informs the **firstFloorButton** of the arrival (message **4.1**), and the **firstFloorButton** resets itself (message **4.1.1**). The **ElevatorShaft** then informs the **firstFloorLight** of the arrival (message **4.2**), and the **firstFloorLight** illuminates itself (message **4.2.1**).

Event Listeners

We demonstrated event handling between the **Elevator** and object **elevatorDoor** using the modified collaboration diagram of Fig. 10.26—the **Elevator** sends an **elevatorArrived** event to the **elevatorDoor** (message **3**). We first must determine the event object that the **Elevator** will pass to the **elevatorDoor**. According to the note in the lower left-hand corner of Fig. 10.26, the **Elevator** passes an **ElevatorMoveEvent** (Fig. 10.27) object when the **Elevator** invokes an **elevatorArrived** method. The generalization diagram of Fig. 10.24 indicates that **ElevatorMoveEvent** is a subclass of **ElevatorModelEvent**, so **ElevatorMoveEvent** inherits the **Object** and **Location** references from **ElevatorModelEvent**.[3]

---

2. The problem of the **waitingPassenger** entering the **Elevator** (message **3.2.1.1**) before the **ridingPassenger** has exited (message **3.3.1**) remains in our collaboration diagram. We show in "Thinking About Objects" Section 15.12 how to solve this problem by using multithreading, synchronization and active classes.
3. In our simulation, all event classes have this structure—that is, the structure of class **ElevatorMoveEvent** is identical to the structure of class **DoorEvent**, **ButtonEvent**, etc. When you have finished reading the material in this section, we recommend that you view the implementation of the events in Appendix G to attain a better comprehension of the structure of our system events—Fig. G.1–G.7 present the code for the events, and Fig. G.8–G.14 present the code for the event listeners.

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```
1  // ElevatorMoveEvent.java
2  // Indicates on which Floor the Elevator arrived or departed
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel package
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class ElevatorMoveEvent extends ElevatorModelEvent {
9
10    // ElevatorMoveEvent constructor
11    public ElevatorMoveEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. 10.27 Class **ElevatorMoveEvent**, a subclass of **ElevatorModelEvent**, is sent when the **Elevator** has arrived at or departed from, a **Floor**.

The **elevatorDoor** must implement an interface that "listens" for an **ElevatorMoveEvent**—this makes the **elevatorDoor** an event listener. Interface **ElevatorMoveListener** (Fig. 10.28) provides methods **elevatorDeparted** (line 8) and **elevatorArrived** (line 11) that enable the **Elevator** to notify the **ElevatorMoveListener** when the **Elevator** has arrived or departed. An interface that provides the methods for an event listener, such as **ElevatorMoveListener**, is called an *event listener interface*.

Methods **elevatorArrived** and **elevatorDeparted** each receive an **ElevatorMoveEvent** (Fig. 10.27) object as an argument. Therefore, when the **Elevator** "sends an **elevatorArrived** event" to another object, the **Elevator** passes an **ElevatorMoveEvent** object as an argument to the receiving object's **elevatorArrived** method. We implement class **Door**—the class of which the **elevatorDoor** is an instance—in Appendix H, after we continue refining our design and learning more Java capabilities.

```
1  // ElevatorMoveListener.java
2  // Methods invoked when Elevator has either departed or arrived
3  package com.deitel.jhtp4.elevator.event;
4
5  public interface ElevatorMoveListener {
6
7     // invoked when Elevator has departed
8     public void elevatorDeparted( ElevatorMoveEvent moveEvent );
9
10    // invoked when Elevator has arrived
11    public void elevatorArrived( ElevatorMoveEvent moveEvent );
12 }
```

Fig. 10.28 Interface **ElevatorMoveListener** provides the methods required to listen for **Elevator** departure and arrival events.

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Class Diagram Revisited

Figure 10.29 modifies the associations in the class diagram of Fig. 9.19 to include event handling. Note that like the collaboration diagram of Fig. 10.26, Fig. 10.29 indicates that an object informs, or *signals*, another object that some event has occurred. If an object receiving the event invokes a **`private`** method, the class diagram represents this method invocation as a *self association*—that is, the class contains an association with itself. The **`Button`**, **`Door`**, **`Light`** and **`Bell`** classes contain self associations; note that the association does not include an arrowhead indicating the direction of the association, because the class's association is with itself. Lastly, the diagram includes an association between class **`Door`** and class **`Person`** (the **`Door`** informs a **`Person`** that the **`Door`** has opened), because we established the relationship between all **`Door`** objects and a **`Person`** object.

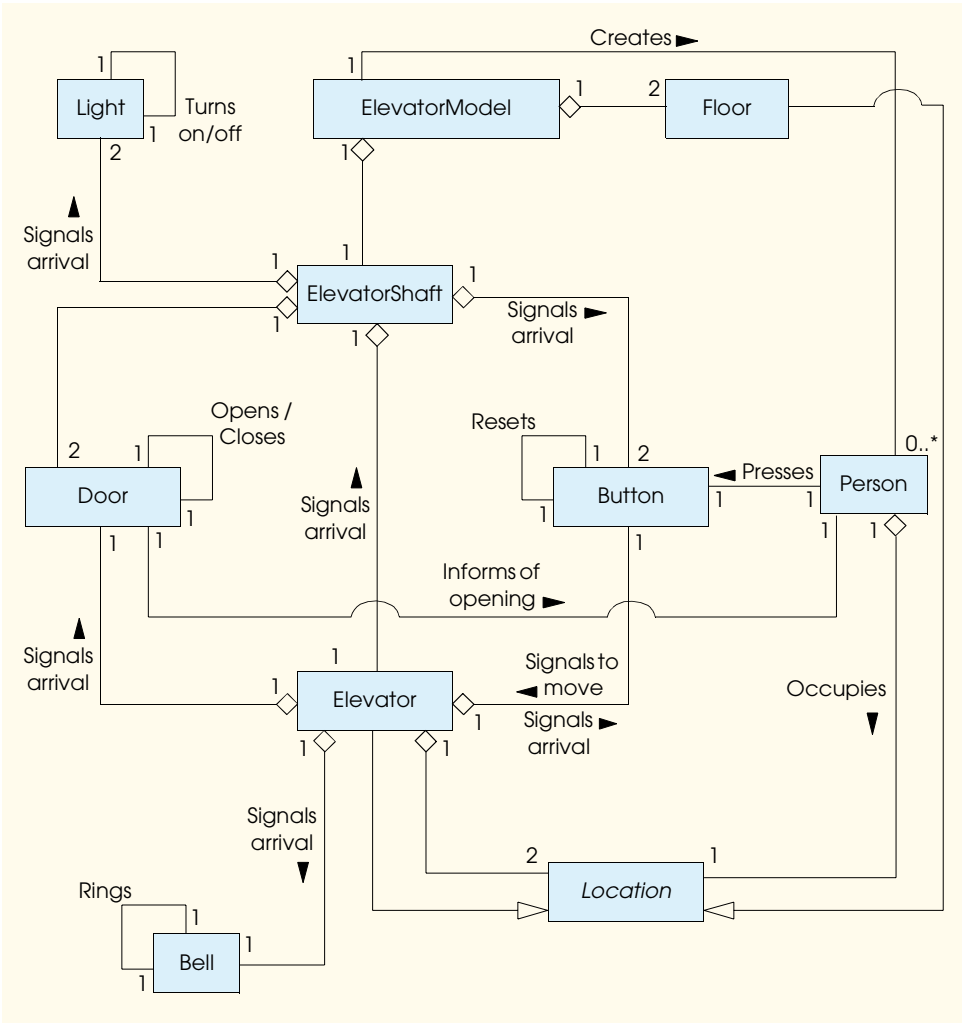

Fig. 10.29 Class diagram of our simulator (including event handling).

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SUMMARY

- A character constant's value is its integer value in the Unicode character set. Strings can include letters, digits and special characters such as **+**, **-**, *****, **/** and **$**. A string in Java is an object of class **String**. String literals or string constants are often referred to as *anonymous* ***String*** *objects* and are written in double quotes in a program.
- Class **String** provides nine constructors.
- **String** method **length** returns the number of characters in a **String**.
- **String** method **charAt** returns the character at a specific position.
- Method **equals** is used to test any two objects for equality (i.e., the contents of the two objects are identical). The method returns **true** if the objects are equal, **false** otherwise. Method **equals** uses a *lexicographical comparison* for **String**s.
- When primitive-data type values are compared with **==**, the result is **true** if both values are identical. When references are compared with **==**, the result is **true** if both references refer to *the same object in memory.*
- Java treats all anonymous **String**s with the same contents as one anonymous **String** object.
- **String** method **equalsIgnoreCase** performs a case-insensitive **String** comparison.
- **String** method **compareTo** returns 0 if the **Strings** it is comparing are equal, a negative number if the **String** that invokes **compareTo** is less than the **String** that is passed as an argument and a positive number if the **String** that invokes **compareTo** is greater than the **String** that is passed as an argument. Method **compareTo** uses a lexicographical comparison.
- **String** method **regionMatches** compares portions of two **String**s for equality.
- **String** method **startsWith** determines whether a **String** starts with the characters specified as an argument. **String** method **endsWith** determines whether a **String** ends with the characters specified as an argument.
- Method **hashCode** performs a hash code calculation that enables a **String** object to be stored in a hash table. This method is inherited from **Object** and overridden by **String**.
- **String** method **indexOf** locates the first occurrence of a character or a substring in a **String**. Method **lastIndexOf** locates the last occurrence of a character or a substring in a **String**.
- **String** method **substring** copies and returns part of an existing **String** object.
- **String** method **concat** concatenates two **String** objects and returns a new **String** object containing the characters from both original **Strings**.
- **String** method **replace** returns a new **String** object that replaces every occurrence in a **String** of its first character argument with its second character argument.
- **String** method **toUpperCase** returns a new **String** with uppercase letters in the positions where the original **String** had lowercase letters. Method **toLowerCase** returns a new **String** with lowercase letters in the positions where the original **String** had uppercase letters.
- **String** method **trim** returns a new **String** object in which all white-space characters (such as spaces, newlines and tabs) have been removed from the beginning or end of a **String**.
- **String** method **toCharArray** returns a new character array containing a copy of the characters in a **String**.
- **String** class method **valueOf** returns its argument converted to a string.
- The first time **String** method **intern** is invoked on a **String** it returns a reference to that **String** object. Subsequent invocations of **intern** on different **String** objects that have the same contents as the original **String** result in multiple references to the original **String** object.

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- Class **StringBuffer** provides three constructors that enable **StringBuffer**s to be initialized with no characters and an initial capacity of 16 characters; with no characters and an initial capacity specified in the integer argument or with a copy of the characters of the **String** argument and an initial capacity that is the number of characters in the **String** argument plus 16.
- **StringBuffer** method **length** returns the number of characters currently stored in a **StringBuffer**. Method **capacity** returns the number of characters that can be stored in a **StringBuffer** without allocating more memory.
- Method **ensureCapacity** ensures that a **StringBuffer** has a minimum capacity. Method **setLength** increases or decreases the length of a **StringBuffer**.
- **StringBuffer** method **charAt** returns the character at the specified index. Method **setCharAt** sets the character at the specified position. Method **getChars** returns a character array containing a copy of the characters in the **StringBuffer**.
- Class **StringBuffer** provides overloaded **append** methods to add primitive data-type, character array, **String** and **Object** values to the end of a **StringBuffer**.
- **StringBuffer**s and the **append** methods are used by the Java compiler to implement the **+** and **+=** operators for concatenating **String**s.
- Class **StringBuffer** provides overloaded **insert** methods to insert primitive data-type, character array, **String** and **Object** values at any position in a **StringBuffer**.
- Class **Character** provides a constructor that takes a character argument.
- **Character** method **isDefined** determines whether a character is defined in the Unicode character set. If so, the method returns **true**; otherwise, it returns **false**.
- **Character** method **isDigit** determines whether a character is a defined Unicode digit. If so, the method returns **true**; otherwise, it returns **false**.
- **Character** method **isJavaIdentifierStart** determines whether a character is a character that can be used as the first character of an identifier in Java [i.e., a letter, an underscore (_) or a dollar sign (**$**)]. If so, the method returns **true**; otherwise, it returns **false**.
- **Character** method **isJavaIdentifierPart** determines whether a character is a character that can be used in an identifier in Java [i.e., a digit, a letter, an underscore (_) or a dollar sign (**$**)]. If so, the method returns **true**; otherwise, it returns **false**. Method **isLetter** determines whether a character is a letter. If so, the method returns **true**; otherwise, it returns **false**. Method **isLetterOrDigit** determines whether a character is a letter or a digit. If so, the method returns **true**; otherwise, it returns **false**.
- **Character** method **isLowerCase** determines whether a character is a lowercase letter. If so, the method returns **true**; otherwise, **false**. **Character** method **isUpperCase** determines if a character is an uppercase letter. If so, the method returns **true**; otherwise, **false**.
- **Character** method **toUpperCase** converts a character to its uppercase equivalent. Method **toLowerCase** converts a character to its lowercase equivalent.
- **Character** method **digit** converts its character argument into an integer in the number system specified by its integer argument **radix**. Method **forDigit** converts its integer argument **digit** into a character in the number system specified by its integer argument **radix**.
- **Character** method **charValue** returns the **char** stored in a **Character** object. Method **toString** returns a **String** representation of a **Character**.
- **Character** method **hashCode** performs a hash code calculation on a **Character**.
- **StringTokenizer**'s default constructor creates a **StringTokenizer** for its **String** argument that will use the default delimiter string **" \n\t\r"**, consisting of a space, a newline, a tab and a carriage return for tokenization.

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- **`StringTokenizer`** method **`countTokens`** returns the number of tokens in a **`String`** to be tokenized.
- **`StringTokenizer`** method **`hasMoreTokens`** determines if there are more tokens in the **`String`** being tokenized.
- **`StringTokenizer`** method **`nextToken`** returns a **`String`** with the next token.

TERMINOLOGY

`append` method of class **`StringBuffer`**
appending strings to other strings
array of strings
`capacity` method of class **`StringBuffer`**
`Character` class
character code
character constant
character set
`charAt` method of class **`String`**
`charAt` method of class **`StringBuffer`**
`charValue` method of class **`Character`**
`compareTo` method of class **`String`**
comparing strings
`concat` method of class **`String`**
concatenation
copying strings
`countTokens` method (**`StringTokenizer`**)
delimiter
`digit` method of class **`Character`**
`endsWith` method of class **`String`**
`equals` method of class **`String`**
`equalsIgnoreCase` method of **`String`**
`forDigit` method of class **`Character`**
`getChars` method of class **`String`**
`getChars` method of class **`StringBuffer`**
hash table
`hashCode` method of class **`Character`**
`hashCode` method of class **`String`**
`hasMoreTokens` method
hexadecimal digits
`indexOf` method of class **`String`**
`insert` method of class **`StringBuffer`**
`intern` method of class **`String`**
`isDefined` method of class **`Character`**
`isDigit` method of class **`Character`**
`isJavaIdentifierPart` method
`isJavaIdentifierStart` method
`isLetter` method of class **`Character`**
`isLetterOrDigit` method of **`Character`**
`isLowerCase` method of class **`Character`**
`isUpperCase` method of class **`Character`**
`lastIndexOf` method of class **`String`**
`length` method of class **`String`**
`length` method of class **`StringBuffer`**
length of a string
literal
`nextToken` method of **`StringTokenizer`**
numeric code representation of a character
printing character
`regionMatches` method of class **`String`**
`replace` method of class **`String`**
search string
`setCharAt` method of class **`StringBuffer`**
`startsWith` method of class **`String`**
string
`String` class
string concatenation
string constant
string literal
string processing
`StringBuffer` class
`StringIndexOutOfBoundsException`
`StringTokenizer` class
`substring` method of **`String`** class
`toCharArray` method of class **`String`**
token
tokenizing strings
`toLowerCase` method of class **`Character`**
`toLowerCase` method of class **`String`**
`toString` method of class **`Character`**
`toString` method of class **`String`**
`toString` method of class **`StringBuffer`**
`toUpperCase` method of class **`Character`**
`toUpperCase` method of class **`String`**
`trim` method of class **`String`**
Unicode
`valueOf` method of class **`String`**
white-space characters
word processing

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SELF-REVIEW EXERCISES

10.1 State whether each of the following is *true* or *false*. If *false*, explain why.

a) When **`String`** objects are compared with **`==`**, the result is **`true`** if the **`String`**s contain the same values.

b) A **`String`** can be modified after it is created.

10.2 For each of the following, write a single statement that performs the indicated task.

a) Compare the string in **`s1`** to the string in **`s2`** for equality of contents.

b) Append the string **`s2`** to the string **`s1`**, using **`+=`**.

c) Determine the length of the string in **`s1`**.

ANSWERS TO SELF-REVIEW EXERCISES

10.1 a) False. **`String`** objects that are compared with operator **`==`** are actually compared to determine if they are the same object in memory.

b) False. **`String`** objects are constant and cannot be modified after they are created. **`StringBuffer`** objects can be modified after they are created.

10.2 a) `s1.equals( s2 )`

b) `s1 += s2;`

c) `s1.length()`

EXERCISES

Exercises 10.3 through 10.6 are reasonably challenging. Once you have done these problems, you ought to be able to implement most popular card games easily.

10.3 Modify the program in Fig. 10.21 so that the card-dealing method deals a five-card poker hand. Then write the following additional methods:

a) Determine if the hand contains a pair.

b) Determine if the hand contains two pairs.

c) Determine if the hand contains three of a kind (e.g., three jacks).

d) Determine if the hand contains four of a kind (e.g., four aces).

e) Determine if the hand contains a flush (i.e., all five cards of the same suit).

f) Determine if the hand contains a straight (i.e., five cards of consecutive face values).

g) Determine if the hand contains a full house (i.e., two cards of one face value and three cards of another face value).

10.4 Use the methods developed in Exercise 10.3 to write a program that deals two five-card poker hands, evaluates each hand and determines which is the better hand.

10.5 Modify the program developed in Exercise 10.4 so that it can simulate the dealer. The dealer's five-card hand is dealt "face down" so the player cannot see it. The program should then evaluate the dealer's hand and, based on the quality of the hand, the dealer should draw one, two or three more cards to replace the corresponding number of unneeded cards in the original hand. The program should then reevaluate the dealer's hand. (*Caution*: This is a difficult problem!)

10.6 Modify the program developed in Exercise 10.5 so that it can handle the dealer's hand automatically, but the player is allowed to decide which cards of the player's hand to replace. The program should then evaluate both hands and determine who wins. Now, use this new program to play 20 games against the computer. Who wins more games, you or the computer? Have one of your friends play 20 games against the computer. Who wins more games? Based on the results of these games, make appropriate modifications to refine your poker-playing program. (This, too, is a difficult problem.) Play 20 more games. Does your modified program play a better game?

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10.7 Write an application that uses **`String`** method **`compareTo`** to compare two strings input by the user. Output whether the first string is less than, equal to or greater than the second.

10.8 Write an application that uses **`String`** method **`regionMatches`** to compare two strings input by the user. The program should input the number of characters to be compared and the starting index of the comparison. The program should state whether the first string is less than, equal to or greater than the second string. Ignore the case of the characters when performing the comparison.

10.9 Write an application that uses random number generation to create sentences. Use four arrays of strings called **`article`**, **`noun`**, **`verb`** and **`preposition`**. Create a sentence by selecting a word at random from each array in the following order: **`article`**, **`noun`**, **`verb`**, **`preposition`**, **`article`** and **`noun`**. As each word is picked, concatenate it to the previous words in the sentence. The words should be separated by spaces. When the final sentence is output, it should start with a capital letter and end with a period. The program should generate 20 sentences and output them to a text area.

The arrays should be filled as follows: The article array should contain the articles **`"the"`**, **`"a"`**, **`"one"`**, **`"some"`** and **`"any"`**; the noun array should contain the nouns **`"boy"`**, **`"girl"`**, **`"dog"`**, **`"town"`** and **`"car"`**; the verb array should contain the verbs **`"drove"`**, **`"jumped"`**, **`"ran"`**, **`"walked"`** and **`"skipped"`**; the preposition array should contain the prepositions **`"to"`**, **`"from"`**, **`"over"`**, **`"under"`** and **`"on"`**.

After the preceding program is written, modify the program to produce a short story consisting of several of these sentences. (How about the possibility of a random term paper writer!)

10.10 *(Limericks)* A limerick is a humorous five-line verse in which the first and second lines rhyme with the fifth, and the third line rhymes with the fourth. Using techniques similar to those developed in Exercise 10.9, write a Java program that produces random limericks. Polishing this program to produce good limericks is a challenging problem, but the result will be worth the effort!

10.11 *(Pig Latin)* Write an application that encodes English language phrases into pig Latin. Pig Latin is a form of coded language often used for amusement. Many variations exist in the methods used to form pig Latin phrases. For simplicity, use the following algorithm:

To form a pig Latin phrase from an English language phrase, tokenize the phrase into words with an object of class StringTokenizer. To translate each English word into a pig Latin word, place the first letter of the English word at the end of the word and add the letters "ay." Thus, the word "jump" becomes "umpjay," the word "the" becomes "hetay," and the word "computer" becomes "omputercay." Blanks between words remain as blanks. Assume the following: The English phrase consists of words separated by blanks, there are no punctuation marks and all words have two or more letters. Method **`printLatinWord`** should display each word. Each token returned from **`nextToken`** is passed to method **`printLatinWord`** to print the pig Latin word. Enable the user to input the sentence. Keep a running display of all the converted sentences in a text area.

10.12 Write an application that inputs a telephone number as a string in the form **`(555) 555-5555`**. The program should use an object of class **`StringTokenizer`** to extract the area code as a token, the first three digits of the phone number as a token and the last four digits of the phone number as a token. The seven digits of the phone number should be concatenated into one string. The program should convert the area code string to **`int`** (remember **`parseInt`**!) and convert the phone number string to **`long`**. Both the area code and the phone number should be printed. Remember that you will have to change delimiter characters during the tokenization process.

10.13 Write an application that inputs a line of text, tokenizes the line with an object of class **`StringTokenizer`** and outputs the tokens in reverse order.

10.14 Use the string comparison methods discussed and the techniques for sorting arrays developed in Chapter 7 to write a program that alphabetizes a list of strings. Allow the user to enter the strings in a text field. Display the results in a text area.

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10.15 Write an application that inputs text and outputs the text in uppercase and lowercase letters.

10.16 Write an application that inputs several lines of text and a search character and uses method **`String`** method **`indexOf`** to determine the number of occurrences of the character in the text.

10.17 Write an application based on the program in Exercise 10.16 that inputs several lines of text and uses **`String`** method **`indexOf`** to determine the total number of occurrences of each letter of the alphabet in the text. Uppercase and lowercase letters should be counted together. Store the totals for each letter in an array and print the values in tabular format after the totals have been determined.

10.18 Write an application that reads a series of strings and outputs only those strings beginning with the letter "**`b`**." The results should be output to a text area.

10.19 Write an application that reads a series of strings and prints only those strings ending with the letters "**`ED`**." The results should be output to a text area.

10.20 Write an application that inputs an integer code for a character and displays the corresponding character. Modify this program so that it generates all possible three-digit codes in the range form 000 to 255 and attempts to print the corresponding characters. Display the results in a text area.

10.21 Write your own versions of the **`String`** methods for searching strings.

10.22 Write a program that reads a five-letter word from the user and produces all possible three-letter words that can be derived from the letters of the five-letter word. For example, the three-letter words produced from the word "bathe" include the commonly used words "ate," "bat," "bet," "tab," "hat," "the" and "tea."

SPECIAL SECTION: ADVANCED STRING MANIPULATION EXERCISES

The preceding exercises are keyed to the text and designed to test the reader's understanding of fundamental string-manipulation concepts. This section includes a collection of intermediate and advanced string-manipulation exercises. The reader should find these problems challenging, yet entertaining. The problems vary considerably in difficulty. Some require an hour or two of program writing and implementation. Others are useful for lab assignments that might require two or three weeks of study and implementation. Some are challenging term projects.

10.23 *(Text Analysis)* The availability of computers with string-manipulation capabilities has resulted in some rather interesting approaches to analyzing the writings of great authors. Much attention has been focused on whether William Shakespeare ever lived. Some scholars believe there is substantial evidence indicating that Christopher Marlowe or other authors actually penned the masterpieces attributed to Shakespeare. Researchers have used computers to find similarities in the writings of these two authors. This exercise examines three methods for analyzing texts with a computer.

a) Write an application that reads several lines of text from the keyboard and prints a table indicating the number of occurrences of each letter of the alphabet in the text. For example, the phrase

```
To be, or not to be: that is the question:
```

contains one "a," two "b's," no "c's," etc.

b) Write an application that reads several lines of text and prints a table indicating the number of one-letter words, two-letter words, three-letter words, etc. appearing in the text. For example, Fig. 10.30 shows the counts for the phrase

```
Whether 'tis nobler in the mind to suffer
```

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Word length	Occurrences
1	0
2	2
3	1
4	2 (including `'tis`)
5	0
6	2
7	1

Fig. 10.30 Counts for the string `"Whether 'tis nobler in the mind to suffer"`.

c) Write an application that reads several lines of text and prints a table indicating the number of occurrences of each different word in the text. The first version of your program should include the words in the table in the same order in which they appear in the text. For example, the lines

```
To be, or not to be: that is the question:
Whether 'tis nobler in the mind to suffer
```

contain the words "to" three times, the word "be" two times, the word "or" once, etc. A more interesting (and useful) printout should then be attempted in which the words are sorted alphabetically.

10.24 *(Printing Dates in Various Formats)* Dates are printed in several common formats. Two of the more common formats are

```
04/25/1955 and April 25, 1955
```

Write an application that reads a date in the first format and prints that date in the second format.

10.25 *(Check Protection)* Computers are frequently employed in check-writing systems such as payroll and accounts payable applications. Many strange stories circulate regarding weekly paychecks being printed (by mistake) for amounts in excess of $1 million. Incorrect amounts are printed by computerized check-writing systems because of human error and/or machine failure. Systems designers build controls into their systems to prevent such erroneous checks from being issued.

Another serious problem is the intentional alteration of a check amount by someone who intends to cash a check fraudulently. To prevent a dollar amount from being altered, most computerized check-writing systems employ a technique called *check protection.*

Checks designed for imprinting by computer contain a fixed number of spaces in which the computer may print an amount. Suppose a paycheck contains eight blank spaces in which the computer is supposed to print the amount of a weekly paycheck. If the amount is large, then all eight of those spaces will be filled, for example:

```
1,230.60  (check amount)
--------
12345678  (position numbers)
```

On the other hand, if the amount is less than $1000, then several of the spaces would ordinarily be left blank. For example,

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```
   99.87
--------
12345678
```

contains three blank spaces. If a check is printed with blank spaces, it is easier for someone to alter the amount of the check. To prevent a check from being altered, many check-writing systems insert *leading asterisks* to protect the amount as follows:

```
***99.87
--------
12345678
```

Write an application that inputs a dollar amount to be printed on a check, then prints the amount in check-protected format with leading asterisks if necessary. Assume that nine spaces are available for printing the amount.

10.26 *(Writing the Word Equivalent of a Check Amount)* Continuing the discussion of the previous exercise, we reiterate the importance of designing check-writing systems to prevent alteration of check amounts. One common security method requires that the check amount be written both in numbers and "spelled out" in words as well. Even if someone is able to alter the numerical amount of the check, it is extremely difficult to change the amount in words.

a) Many computerized check-writing systems do not print the amount of the check in words. Perhaps the main reason for this omission is the fact that most high-level languages used in commercial applications do not contain adequate string-manipulation features. Another reason is that the logic for writing word equivalents of check amounts is somewhat involved.

b) Write an application that inputs a numeric check amount and writes the word equivalent of the amount. For example, the amount 112.43 should be written as

```
ONE HUNDRED TWELVE and 43/100
```

10.27 *(Morse Code)* Perhaps the most famous of all coding schemes is the Morse code, developed by Samuel Morse in 1832 for use with the telegraph system. The Morse code assigns a series of dots and dashes to each letter of the alphabet, each digit, and a few special characters (such as period, comma, colon and semicolon). In sound-oriented systems, the dot represents a short sound and the dash represents a long sound. Other representations of dots and dashes are used with light-oriented systems and signal-flag systems.

Separation between words is indicated by a space, or, quite simply, the absence of a dot or dash. In a sound-oriented system, a space is indicated by a short period of time during which no sound is transmitted. The international version of the Morse code appears in Fig. 10.31.

Write an application that reads an English language phrase and encodes the phrase into Morse code. Also write a program that reads a phrase in Morse code and converts the phrase into the English language equivalent. Use one blank between each Morse-coded letter and three blanks between each Morse-coded word.

10.28 *(A Metric Conversion Program)* Write an application that will assist the user with metric conversions. Your program should allow the user to specify the names of the units as strings (i.e., centimeters, liters, grams, etc. for the metric system and inches, quarts, pounds, etc. for the English system) and should respond to simple questions such as

```
"How many inches are in 2 meters?"
"How many liters are in 10 quarts?"
```

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Character	Code	Character	Code
A	.-	T	-
B	-...	U	..-
C	-.-.	V	...-
D	-..	W	.--
E	.	X	-..-
F	..-.	Y	-.--
G	--.	Z	--..
H	....		
I	..	Digits	
J	.---	1	.----
K	-.-	2	..---
L	.-..	3	...--
M	--	4	....-
N	-.	5	.....
O	---	6	-....
P		7	--...
Q	--.-	8	---..
R	.-.	9	----.
S	...	0	-----

Fig. 10.31 The letters of the alphabet as expressed in international Morse code .

Your program should recognize invalid conversions. For example, the question

```
"How many feet in 5 kilograms?"
```

is not a meaningful question because **"feet"** is a unit of length while **"kilograms"** is a unit of mass.

SPECIAL SECTION: CHALLENGING STRING MANIPULATION PROJECTS

10.29 *(Project: A Spelling Checker)* Many popular word processing software packages have built-in spell checkers.

In this project, you are asked to develop your own spell-checker utility. We make suggestions to help get you started. You should then consider adding more capabilities. Use a computerized dictionary (if you have access to one) as a source of words.

Why do we type so many words with incorrect spellings? In some cases, it is because we simply do not know the correct spelling, so we make a "best guess." In some cases, it is because we transpose two letters (e.g., "defualt" instead of "default"). Sometimes we double-type a letter accidentally (e.g., "hanndy" instead of "handy"). Sometimes we type a nearby key instead of the one we intended (e.g., "biryhday" instead of "birthday"), and so on.

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Design and implement a spell-checker application in Java. Your program should maintain an array **`wordList`** of strings. Enable the user to enter these strings. [*Note*: In Chapter 17, we introduce file processing. Once you have this capability, you can obtain the words for the spell checker from a computerized dictionary stored in a file.]

Your program should ask a user to enter a word. The program should then look up that word in the **`wordList`** array. If the word is present in the array, your program should print "**`Word is spelled correctly`**."

If the word is not present in the array, your program should print "**`word is not spelled correctly`**." Then your program should try to locate other words in **`wordList`** that might be the word the user intended to type. For example, you can try all possible single transpositions of adjacent letters to discover that the word "default" is a direct match to a word in **`wordList`**. Of course, this implies that your program will check all other single transpositions, such as "edfault," "dfeault," "deafult," "defalut," and "defautl." When you find a new word that matches one in **`wordList`**, print that word in a message, such as "**`Did you mean "default?"`**."

Implement other tests, such as replacing each double letter with a single letter and any other tests you can develop to improve the value of your spell-checker.

10.30 *(Project: A Crossword Puzzle Generator)* Most people have worked a crossword puzzle, but few have ever attempted to generate one. Generating a crossword puzzle is suggested here as a string-manipulation project requiring substantial sophistication and effort.

There are many issues the programmer must resolve to get even the simplest crossword puzzle-generator program working. For example, how does one represent the grid of a crossword puzzle inside the computer? Should one use a series of strings, or should double-subscripted arrays be used?

The programmer needs a source of words (i.e., a computerized dictionary) that can be directly referenced by the program. In what form should these words be stored to facilitate the complex manipulations required by the program?

The really ambitious reader will want to generate the "clues" portion of the puzzle, in which the brief hints for each "across" word and each "down" word are printed for the puzzle worker. Merely printing a version of the blank puzzle itself is not a simple problem.

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11

Graphics and Java2D

Objectives

- To understand graphics contexts and graphics objects.
- To understand and be able to manipulate colors.
- To understand and be able to manipulate fonts.
- To use **`Graphics`** methods to draw lines, rectangles, rectangles with rounded corners, three-dimensional rectangles, ovals, arcs and polygons.
- To use methods of class **`Graphics2D`** from the Java2D API to draw lines, rectangles, rectangles with rounded corners, ellipses, arcs and general paths.
- To be able to specify **`Paint`** and **`Stroke`** characteristics of shapes displayed with **`Graphics2D`**.

One picture is worth ten thousand words.
Chinese proverb

Treat nature in terms of the cylinder, the sphere, the cone, all in perspective.
Paul Cezanne

Nothing ever becomes real till it is experienced—even a proverb is no proverb to you till your life has illustrated it.
John Keats

A picture shows me at a glance what it takes dozens of pages of a book to expound.
Ivan Sergeyevich Turgenev

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Outline

11.1 Introduction
11.2 Graphics Contexts and Graphics Objects
11.3 Color Control
11.4 Font Control
11.5 Drawing Lines, Rectangles and Ovals
11.6 Drawing Arcs
11.7 Drawing Polygons and Polylines
11.8 The Java2D API
11.9 Java2D Shapes
11.10 (Optional Case Study) Thinking About Objects: Designing Interfaces with the UML

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

11.1 Introduction

In this chapter, we overview several of Java's capabilities for drawing two-dimensional shapes, controlling colors and controlling fonts. One of Java's initial appeals was its support for graphics that enabled Java programmers to visually enhance their applets and applications. Java now contains many more sophisticated drawing capabilities as part of the *Java2D API*. This chapter begins with an introduction to many of the original drawing capabilities of Java. Next, we present several of the new and more powerful Java2D capabilities, such as controlling the style of lines used to draw shapes and controlling how shapes are filled with color and patterns.

Figure 11.1 shows a portion of the Java class hierarchy that includes several of the basic graphics classes and Java2D API classes and interfaces covered in this chapter. Class **`Color`** contains methods and constants for manipulating colors. Class **`Font`** contains methods and constants for manipulating fonts. Class **`FontMetrics`** contains methods for obtaining font information. Class **`Polygon`** contains methods for creating polygons. Class **`Graphics`** contains methods for drawing strings, lines, rectangles and other shapes. The bottom half of the figure lists several classes and interfaces from the Java2D API. Class **`BasicStroke`** helps specify the drawing characteristics of lines. Classes **`GradientPaint`** and **`TexturePaint`** help specify the characteristics for filling shapes with colors or patterns. Classes **`GeneralPath`**, **`Arc2D`**, **`Ellipse2D`**, **`Line2D`**, **`Rectangle2D`** and **`RoundRectangle2D`** define a variety of Java2D shapes.

To begin drawing in Java, we must first understand Java's *coordinate system* (Figure 11.2), which is a scheme for identifying every possible point on the screen. By default, the upper-left corner of a GUI component (such as an applet or a window) has the coordinates (0, 0). A coordinate pair is composed of an *x-coordinate* (the *horizontal coordinate*) and a *y-coordinate* (the *vertical coordinate*). The *x*-coordinate is the horizontal distance moving right from the upper-left corner. The *y*-coordinate is the vertical distance moving down from the upper-left corner. The *x-axis* describes every horizontal coordinate, and the *y-axis* describes every vertical coordinate.

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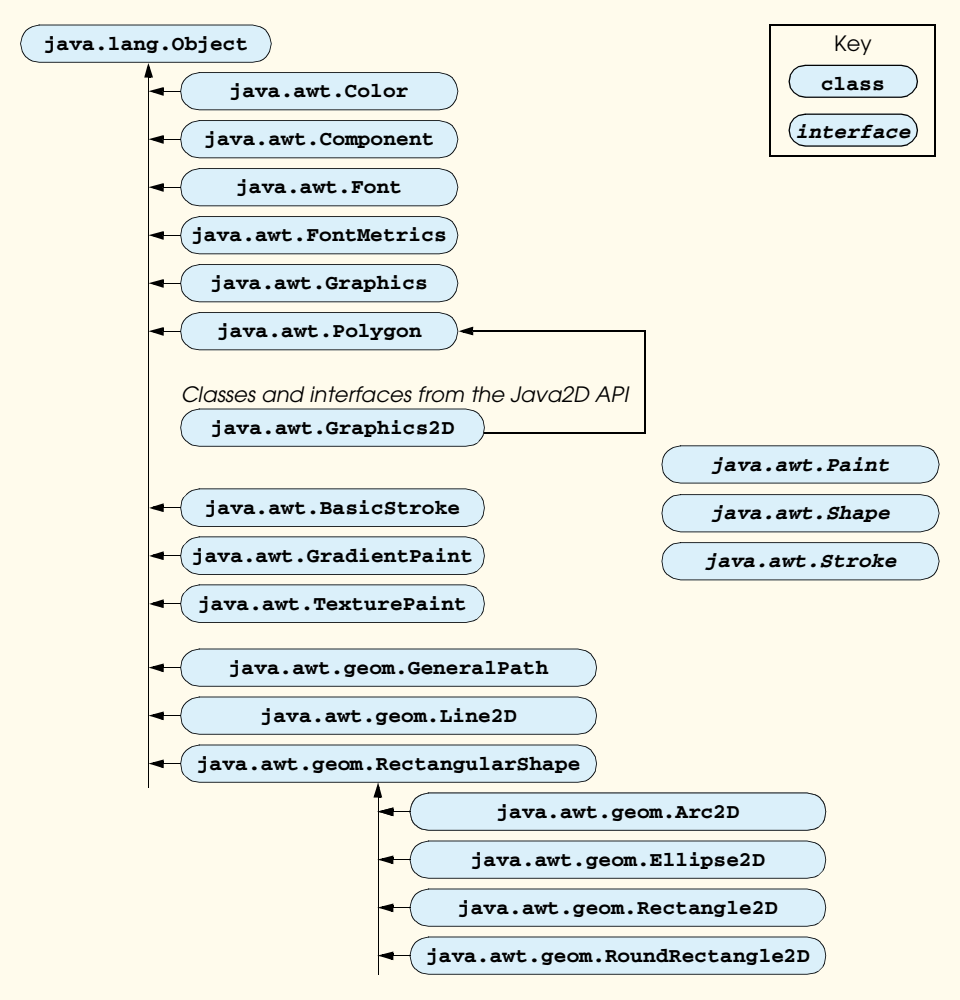

Fig. 11.1 Some classes and interfaces used in this chapter from Java's original graphics capabilities and from the Java2D API.

Software Engineering Observation 11.1

The upper-left coordinate (0, 0) of a window is actually behind the title bar of the window. For this reason, drawing coordinates should be adjusted to draw inside the borders of the window. Class **`Container`** *(a superclass of all windows in Java) has method* **`getInsets`**, *which returns an* **`Insets`** *object (package* **`java.awt`**) *for this purpose. An* **`Insets`** *object has four* **`public`** *members—***`top`**, **`bottom`**, **`left`** *and* **`right`***—that represent the number of pixels from each edge of the window to the drawing area for the window.*

Text and shapes are displayed on the screen by specifying coordinates. Coordinate units are measured in *pixels*. A pixel is a display monitor's smallest unit of resolution.

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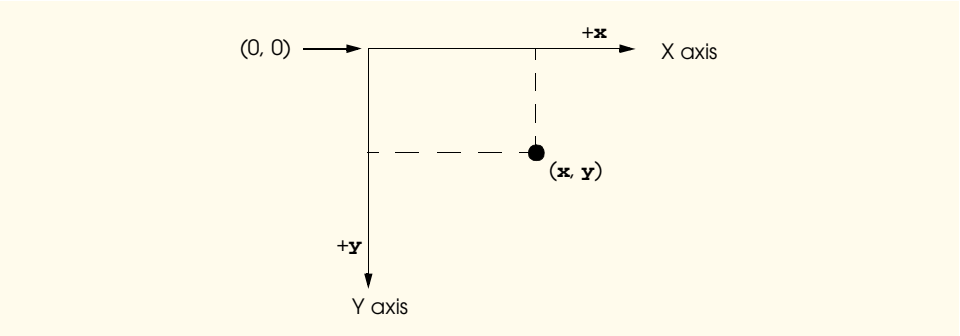

Fig. 11.2 Java coordinate system. Units are measured in pixels.

Portability Tip 11.1

Different display monitors have different resolutions (i.e., the density of pixels varies). This can cause graphics to appear to be different sizes on different monitors.

11.2 Graphics Contexts and Graphics Objects

A Java *graphics context* enables drawing on the screen. A Graphics object manages a graphics context by controlling how information is drawn. Graphics objects contain methods for drawing, font manipulation, color manipulation and the like. Every applet we have seen in the text that performs drawing on the screen has used the **Graphics** object **g** (the argument to the applet's **paint** method) to manage the applet's graphics context. In this chapter, we demonstrate drawing in applications. However, every technique shown here can be used in applets.

The **Graphics** class is an **abstract** class (i.e., **Graphics** objects cannot be instantiated). This contributes to Java's portability. Because drawing is performed differently on each platform that supports Java, there cannot be one class that implements drawing capabilities on all systems. For example, the graphics capabilities that enable a PC running Microsoft Windows to draw a rectangle are different from the graphics capabilities that enable a UNIX workstation to draw a rectangle—and those are both different from the graphics capabilities that enable a Macintosh to draw a rectangle. When Java is implemented on each platform, a derived class of **Graphics** is created that actually implements all the drawing capabilities. This implementation is hidden from us by the **Graphics** class, which supplies the interface that enables us to write programs that use graphics in a platform-independent manner.

Class **Component** is the superclass for many of the classes in the **java.awt** package (we discuss class **Component** in Chapter 12). **Component** method **paint** takes a **Graphics** object as an argument. This object is passed to the **paint** method by the system when a **paint** operation is required for a **Component**. The header for the **paint** method is

```
public void paint( Graphics g )
```

The **Graphics** object **g** receives a reference to an object of the system's derived **Graphics** class. The preceding method header should look familiar to you—it is the same one

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we have been using in our applet classes. Actually, the **Component** class is an indirect base class of class **JApplet**—the superclass of every applet in this book. Many capabilities of class **JApplet** are inherited from class **Component**. The paint method defined in class **Component** does nothing by default—it must be overridden by the programmer.

The paint method is seldom called directly by the programmer because drawing graphics is an *event-driven process*. When an applet executes, the paint method is automatically called (after calls to the **JApplet**'s **init** and **start** methods). For paint to be called again, an *event* must occur (such as covering and uncovering the applet). Similarly, when any **Component** is displayed, that **Component**'s **paint** method is called.

If the programmer needs to call **paint**, a call is made to the **Component** class **repaint** method. Method **repaint** requests a call to the **Component** class **update** method as soon as possible to clear the **Component**'s background of any previous drawing, then **update** calls **paint** directly. The repaint method is frequently called by the programmer to force a paint operation. Method **repaint** should not be overridden, because it performs some system-dependent tasks. The **update** method is seldom called directly and sometimes overridden. Overriding the **update** method is useful for "smoothing" animations (i.e., reducing "flicker") as we will discuss in Chapter 18, Multimedia. The headers for **repaint** and **update** are

```
public void repaint()
public void update( Graphics g )
```

Method **update** takes a **Graphics** object as an argument, which is supplied automatically by the system when **update** is called.

In this chapter, we focus on the **paint** method. In the next chapter, we concentrate more on the event-driven nature of graphics and discuss the **repaint** and **update** methods in more detail. We also discuss in that chapter class **JComponent**—a superclass of many GUI components in package **javax.swing**. Subclasses of **JComponent** typically paint from their **paintComponent** methods.

11.3 Color Control

Colors enhance the appearance of a program and help convey meaning. For example, a traffic light has three different color lights—red indicates stop, yellow indicates caution and green indicates go.

Class ***Color*** defines methods and constants for manipulating colors in a Java program. The predefined color constants are summarized in Fig. 11.3, and several color methods and constructors are summarized in Fig. 11.4. Note that two of the methods in Fig. 11.4 are **Graphics** methods that are specific to colors.

Every color is created from a red, a green and a blue component. Together these components are called *RGB values*. All three RGB components can be integers in the range from 0 to 255, or all three RGB parts can be floating-point values in the range 0.0 to 1.0. The first RGB part defines the amount of red, the second defines the amount of green and the third defines the amount of blue. The larger the RGB value, the greater the amount of that particular color. Java enables the programmer to choose from 256 × 256 × 256 (or approximately 16.7 million) colors. However, not all computers are capable of displaying all these colors. If this is the case, the computer will display the closest color it can.

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`Color` Constant	Color	RGB value
`public final static Color orange`	orange	255, 200, 0
`public final static Color pink`	pink	255, 175, 175
`public final static Color cyan`	cyan	0, 255, 255
`public final static Color magenta`	magenta	255, 0, 255
`public final static Color yellow`	yellow	255, 255, 0
`public final static Color black`	black	0, 0, 0
`public final static Color white`	white	255, 255, 255
`public final static Color gray`	gray	128, 128, 128
`public final static Color lightGray`	light gray	192, 192, 192
`public final static Color darkGray`	dark gray	64, 64, 64
`public final static Color red`	red	255, 0, 0
`public final static Color green`	green	0, 255, 0
`public final static Color blue`	blue	0, 0, 255

Fig. 11.3 `Color` class `static` constants and RGB values

Method	Description
`public Color( int r, int g, int b )`	Creates a color based on red, green and blue contents expressed as integers from 0 to 255.
`public Color( float r, float g, float b )`	Creates a color based on red, green and blue contents expressed as floating-point values from 0.0 to 1.0.
`public int getRed()  // Color class`	Returns a value between 0 and 255 representing the red content.
`public int getGreen()  // Color class`	Returns a value between 0 and 255 representing the green content.
`public int getBlue()  // Color class`	Returns a value between 0 and 255 representing the blue content.
`public Color getColor()  // Graphics class`	Returns a `Color` object representing the current color for the graphics context.
`public void setColor( Color c ) // Graphics class`	Sets the current color for drawing with the graphics context.

Fig. 11.4 `Color` methods and color-related `Graphics` methods .

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Common Programming Error 11.1

Spelling any **`static Color`** *class constant with an initial capital letter is a syntax error.*

Two **`Color`** constructors are shown in Fig. 11.4—one that takes three **`int`** arguments, and one that takes three **`float`** arguments, with each argument specifying the amount of red, green and blue, respectively. The int values must be between 0 and 255 and the **`float`** values must be between 0.0 and 1.0. The new **`Color`** object will have the specified amounts of red, green and blue. **`Color`** methods **`getRed`**, **`getGreen`** and **`getBlue`** return integer values from 0 to 255 representing the amount of red, green and blue, respectively. **`Graphics`** method **`getColor`** returns a **`Color`** object representing the current drawing color. **`Graphics`** method **`setColor`** sets the current drawing color.

The application of Fig. 11.5 demonstrates several methods from Fig. 11.4 by drawing filled rectangles and strings in several different colors.

```
1  // Fig. 11.5: ShowColors.java
2  // Demonstrating Colors.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class ShowColors extends JFrame {
12
13    // constructor sets window's title bar string and dimensions
14    public ShowColors()
15    {
16       super( "Using colors" );
17
18       setSize( 400, 130 );
19       setVisible( true );
20    }
21
22    // draw rectangles and Strings in different colors
23    public void paint( Graphics g )
24    {
25       // call superclass's paint method
26       super.paint( g );
27
28       // set new drawing color using integers
29       g.setColor( new Color( 255, 0, 0 ) );
30       g.fillRect( 25, 25, 100, 20 );
31       g.drawString( "Current RGB: " + g.getColor(), 130, 40 );
32
33       // set new drawing color using floats
34       g.setColor( new Color( 0.0f, 1.0f, 0.0f ) );
35       g.fillRect( 25, 50, 100, 20 );
36       g.drawString( "Current RGB: " + g.getColor(), 130, 65 );
```

Fig. 11.5 Demonstrating setting and getting a **`Color`** (part 1 of 2).

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```
37
38          // set new drawing color using static Color objects
39          g.setColor( Color.blue );
40          g.fillRect( 25, 75, 100, 20 );
41          g.drawString( "Current RGB: " + g.getColor(), 130, 90 );
42
43          // display individual RGB values
44          Color color = Color.magenta;
45          g.setColor( color );
46          g.fillRect( 25, 100, 100, 20 );
47          g.drawString( "RGB values: " + color.getRed() + ", " +
48             color.getGreen() + ", " + color.getBlue(), 130, 115 );
49       }
50
51       // execute application
52       public static void main( String args[] )
53       {
54          ShowColors application = new ShowColors();
55
56          application.setDefaultCloseOperation(
57             JFrame.EXIT_ON_CLOSE );
58       }
59
60    }  // end class ShowColors
```

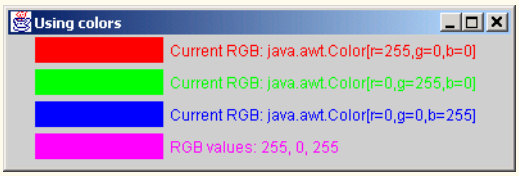

Fig. 11.5 Demonstrating setting and getting a **Color** (part 2 of 2).

When the application begins execution, class **ShowColors**'s **paint** method (lines 23–49) is called to paint the window. Line 29 uses **Graphics** method **setColor** to set the current drawing color. Method **setColor** receives a **Color** object. The expression **new Color(255, 0, 0)** creates a new **Color** object that represents red (red value **255**, and **0** for the green and blue values). Line 30 uses **Graphics** method **fillRect** to draw a filled rectangle in the current color. Method **fillRect** receives the same parameters as method **drawRect** (discussed in Chapter 3). Line 31uses **Graphics** method **drawString** to draw a **String** in the current color. The expression **g.getColor()** retrieves the current color from the **Graphics** object. The returned **Color** is concatenated with string **"Current RGB: "**, resulting in an implicit call to class **Color**'s **toString** method. Notice that the **String** representation of the **Color** object contains the class name and package (**java.awt.Color**), and the red, green and blue values.

Lines 34–36 and lines 39–41 perform the same tasks again. Line 34 uses the **Color** constructor with three **float** arguments to create the color green (**0.0f** for red, **1.0f** for green and **0.0f** for blue). Note the syntax of the constants. The letter **f** appended to a floating-point constant indicates that the constant should be treated as type **float**. Normally, floating-point constants are treated as type **double**.

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Line 39 sets the current drawing color to one of the predefined **Color** constants (**Color.blue**). Note that the new operator is not needed to create the constant. The **Color** constants are **static**, so they are defined when class **Color** is loaded into memory at execution time.

The statement at lines 47–48 demonstrates **Color** methods **getRed**, **getGreen** and **getBlue** on the predefined **Color.magenta** object.

Notice lines 56–57 in **main**. **JFrame** method **setDefaultCloseOperation** specifies the default action to take when the user clicks the close box on an application window. In this case, we specify ***JFrame.EXIT_ON_CLOSE*** to indicate that the program should terminate when the user clicks the close box. Other options are **DO_NOTHING_ON_CLOSE** (to ignore the window-closing event), **HIDE_ON_CLOSE** (to hide the window, such that it can be redisplayed later) and **DISPOSE_ON_CLOSE** (to dispose of the window, such that it cannot be redisplayed later). From this point forward, we implement our own **WindowListener** only if the program should perform additional tasks when the user clicks the window's close box. Otherwise, we use method **setDefaultCloseOperation** to specify that the program should terminate when the user clicks the close box.

Software Engineering Observation 11.2

*To change the color, you must create a new **Color** object (or use one of the predefined **Color** constants); there are no set methods in class **Color** to change the characteristics of the current color.*

One of the newer features of Java is the predefined GUI component ***JColorChooser*** (package **javax.swing**) for selecting colors. The application of Fig. 11.6 enables you to press a button to display a **JColorChooser** dialog. When you select a color and press the dialog's **OK** button, the background color of the application window changes colors.

```
1  // Fig. 11.6: ShowColors2.java
2  // Demonstrating JColorChooser.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class ShowColors2 extends JFrame {
12    private JButton changeColorButton;
13    private Color color = Color.lightGray;
14    private Container container;
15
16    // set up GUI
17    public ShowColors2()
18    {
19       super( "Using JColorChooser" );
20
```

Fig. 11.6 Demonstrating the **JColorChooser** dialog (part 1 of 3).

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```
21          container = getContentPane();
22          container.setLayout( new FlowLayout() );
23
24          // set up changeColorButton and register its event handler
25          changeColorButton = new JButton( "Change Color" );
26
27          changeColorButton.addActionListener(
28
29             // anonymous inner class
30             new ActionListener() {
31
32                // display JColorChooser when user clicks button
33                public void actionPerformed( ActionEvent event )
34                {
35                   color = JColorChooser.showDialog(
36                      ShowColors2.this, "Choose a color", color );
37
38                   // set default color, if no color is returned
39                   if ( color == null )
40                      color = Color.lightGray;
41
42                   // change content pane's background color
43                   container.setBackground( color );
44                }
45
46             }  // end anonymous inner class
47
48          ); // end call to addActionListener
49
50          container.add( changeColorButton );
51
52          setSize( 400, 130 );
53          setVisible( true );
54       }
55
56       // execute application
57       public static void main( String args[] )
58       {
59          ShowColors2 application = new ShowColors2();
60
61          application.setDefaultCloseOperation(
62             JFrame.EXIT_ON_CLOSE );
63       }
64
65    }  // end class ShowColors2
```

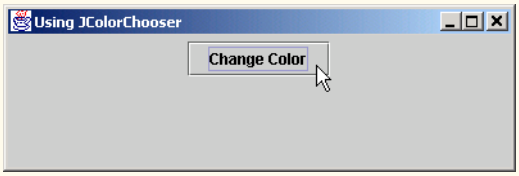

Fig. 11.6 Demonstrating the **JColorChooser** dialog (part 2 of 3).

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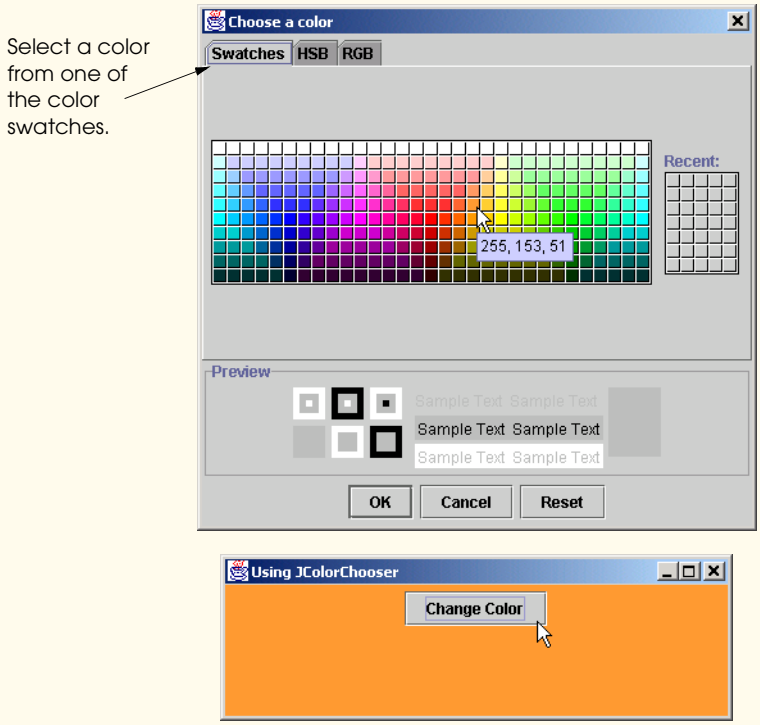

Fig. 11.6 Demonstrating the **`JColorChooser`** dialog (part 3 of 3).

Lines 35–36 (from method **`actionPerformed`** for **`changeColor`**) use **`static`** method ***`showDialog`*** of class **`JColorChooser`** to display the color chooser dialog. This method returns the selected **`Color`** object (**`null`**, if the user presses **Cancel** or closes the dialog without pressing **OK**).

Method **`showDialog`** takes three arguments—a reference to its parent **`Component`**, a **`String`** to display in the title bar of the dialog and the initial selected **`Color`** for the dialog. The parent component is the window from which the dialog is displayed. While the color chooser dialog is on the screen, the user cannot interact with the parent component. This type of dialog is called a *modal dialog* and is discussed in Chapter 13. Notice the special syntax **`ShowColors2.this`** used in the preceding statement. When using an inner class, you can access the outer class object's **`this`** reference by qualifying **`this`** with the name of the outer class and the dot (**`.`**) operator.

After the user selects a color, lines 39–40 determine whether **`color`** is **`null`**, and, if so, set **`color`** to the default **`Color.lightGray`**. Line 43 uses method **`setBackground`** to change the background color of the content pane (represented by **`container`** in this program). Method **`setBackground`** is one of the many **`Component`** methods that can be used on most GUI components.

The second screen capture of Fig. 11.6 demonstrates the default **`JColorChooser`** dialog that allows the user to select a color from a variety of *color swatches*. Notice that there are actually three tabs across the top of the dialog—***Swatches***, ***HSB*** and ***RGB***.

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These represent three different ways to select a color. The **HSB** tab allows you to select a color based on *hue*, *saturation* and *brightness*. The **RGB** tab allows you to select a color by using sliders to select the red, green and blue components of the color. The **HSB** and **RGB** tabs are shown in Fig. 11.7.

11.4 Font Control

This section introduces methods and constants for font control. Most font methods and font constants are part of class Font. Some methods of class **`Font`** and class **`Graphics`** are summarized in Fig. 11.8.

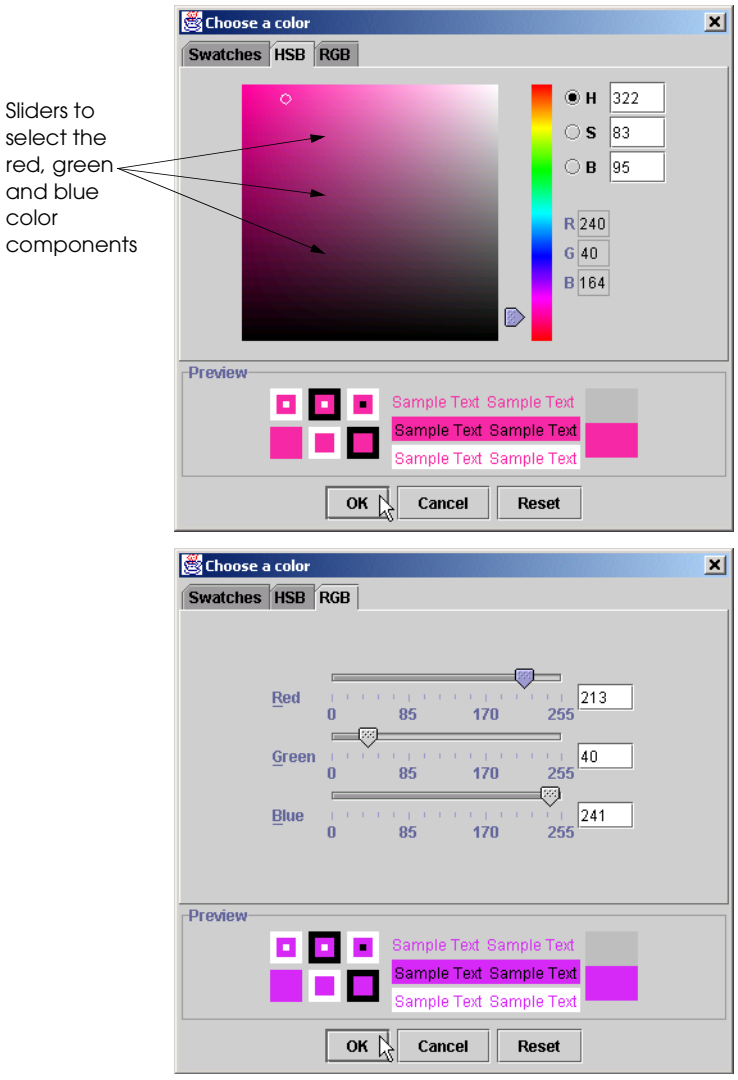

Fig. 11.7 The **HSB** and **RGB** tabs of the **`JColorChooser`** dialog.

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Method or constant	Description
`public final static int PLAIN // Font class`	A constant representing a plain font style.
`public final static int BOLD // Font class`	A constant representing a bold font style.
`public final static int ITALIC // Font class`	A constant representing an italic font style.
`public Font( String name, int style, int size )`	Creates a **`Font`** object with the specified font, style and size.
`public int getStyle() // Font class`	Returns an integer value indicating the current font style.
`public int getSize() // Font class`	Returns an integer value indicating the current font size.
`public String getName() // Font class`	Returns the current font name as a string.
`public String getFamily() // Font class`	Returns the font's family name as a string.
`public boolean isPlain() // Font class`	Tests a font for a plain font style. Returns **`true`** if the font is plain.
`public boolean isBold() // Font class`	Tests a font for a bold font style. Returns **`true`** if the font is bold.
`public boolean isItalic() // Font class`	Tests a font for an italic font style. Returns **`true`** if the font is italic.
`public Font getFont() // Graphics class`	Returns a **`Font`** object reference representing the current font.
`public void setFont( Font f ) // Graphics class`	Sets the current font to the font, style and size specified by the **`Font`** object reference **`f`**.

Fig. 11.8 **`Font`** methods, constants and font-related **`Graphics`** methods .

Class **`Font`**'s constructor takes three arguments—the *font name*, *font style* and *font size*. The font name is any font currently supported by the system where the program is running, such as standard Java fonts **`Monospaced`**, **`SansSerif`** and **`Serif`**. The font style is **`Font.PLAIN`**, **`Font.ITALIC`** or **`Font.BOLD`** (**`static`** constants of class **`Font`**). Font styles can be used in combination (e.g., **`Font.ITALIC + Font.BOLD`**). The font size is measured in points. A *point* is 1/72 of an inch. **`Graphics`** method **`setFont`** sets the current drawing font—the font in which text will be displayed—to its **`Font`** argument.

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Portability Tip 11.2

The number of fonts varies greatly across systems. The J2SDK guarantees that the fonts ***Serif****,* ***Monospaced****,* ***SansSerif****,* ***Dialog*** *and* ***DialogInput*** *will be available.*

Common Programming Error 11.2

Specifying a font that is not available on a system is a logic error. Java will substitute that system's default font.

The program of Fig. 11.9 displays text in four different fonts, with each font in a different size. The program uses the **Font** constructor to initialize **Font** objects on lines 30, 35, 40 and 47 (each in a call to **Graphics** method **setFont** to change the drawing font). Each call to the Font constructor passes a font name (**Serif**, **Monospaced** or **SansSerif**) as a **String**, a font style (**Font.PLAIN**, **Font.ITALIC** or **Font.BOLD**) and a font size. Once **Graphics** method setFont is invoked, all text displayed following the call will appear in the new font until the font is changed. Note that line 35 changes the drawing color to red, so the next string displayed appears in red.

```
1  // Fig. 11.9: Fonts.java
2  // Using fonts
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class Fonts extends JFrame {
12
13    // set window's title bar and dimensions
14    public Fonts()
15    {
16       super( "Using fonts" );
17
18       setSize( 420, 125 );
19       setVisible( true );
20    }
21
22    // display Strings in different fonts and colors
23    public void paint( Graphics g )
24    {
25       // call superclass's paint method
26       super.paint( g );
27
28       // set current font to Serif (Times), bold, 12pt
29       // and draw a string
30       g.setFont( new Font( "Serif", Font.BOLD, 12 ) );
31       g.drawString( "Serif 12 point bold.", 20, 50 );
32
```

Fig. 11.9 Using **Graphics** method **setFont** to change **Font**s (part 1 of 2).

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```
33          // set current font to Monospaced (Courier),
34          // italic, 24pt and draw a string
35          g.setFont( new Font( "Monospaced", Font.ITALIC, 24 ) );
36          g.drawString( "Monospaced 24 point italic.", 20, 70 );
37
38          // set current font to SansSerif (Helvetica),
39          // plain, 14pt and draw a string
40          g.setFont( new Font( "SansSerif", Font.PLAIN, 14 ) );
41          g.drawString( "SansSerif 14 point plain.", 20, 90 );
42
43          // set current font to Serif (times), bold/italic,
44          // 18pt and draw a string
45          g.setColor( Color.red );
46          g.setFont(
47             new Font( "Serif", Font.BOLD + Font.ITALIC, 18 ) );
48          g.drawString( g.getFont().getName() + " " +
49             g.getFont().getSize() +
50             " point bold italic.", 20, 110 );
51       }
52
53       // execute application
54       public static void main( String args[] )
55       {
56          Fonts application = new Fonts();
57
58          application.setDefaultCloseOperation(
59             JFrame.EXIT_ON_CLOSE );
60       }
61
62    }  // end class Fonts
```

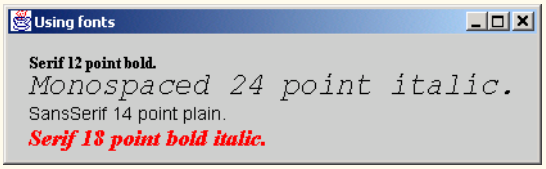

Fig. 11.9 Using **Graphics** method **setFont** to change **Font**s (part 2 of 2).

Software Engineering Observation 11.3

To change the font, you must create a new **Font** *object; there are no* set *methods in class* **Font** *to change the characteristics of the current font.*

Often, it is necessary to get information about the current font, such as the font name, the font style and the font size. Several **Font** methods used to get font information are summarized in Fig. 11.8. Method **getStyle** returns an integer value representing the current style. The integer value returned is either **Font.PLAIN**, **Font.ITALIC**, **Font.BOLD** or any combination of **Font.PLAIN**, **Font.ITALIC** and **Font.BOLD**.

Method **getSize** returns the font size in points. Method **getName** returns the current font name as a **String**. Method **getFamily** returns the name of the font family to which the current font belongs. The name of the font family is platform specific.

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Portability Tip 11.3

Java provides several standardized font names and maps these into system-specific font names for portability. This is transparent to the programmer.

Font methods are also available to test the style of the current font and are summarized in Fig. 11.8. The **`isPlain`** method returns **`true`** if the current font style is plain. The **`isBold`** method returns **`true`** if the current font style is bold. The **`isItalic`** method returns **`true`** if the current font style is italic.

Sometimes precise information about a font's metrics must be known—such as *height*, *descent* (the amount a character dips below the baseline), *ascent* (the amount a character rises above the baseline) and *leading* (the difference between the descent of one line of text and the ascent of the line of text below it—i.e., the interline spacing). Figure 11.10 illustrates some of the common *font metrics*. Note that the coordinate passed to **`drawString`** corresponds to the lower-left corner of the baseline of the font.

Class ***`FontMetrics`*** defines several methods for obtaining font metrics. These methods and **`Graphics`** method ***`getFontMetrics`*** are summarized in Fig. 11.11.

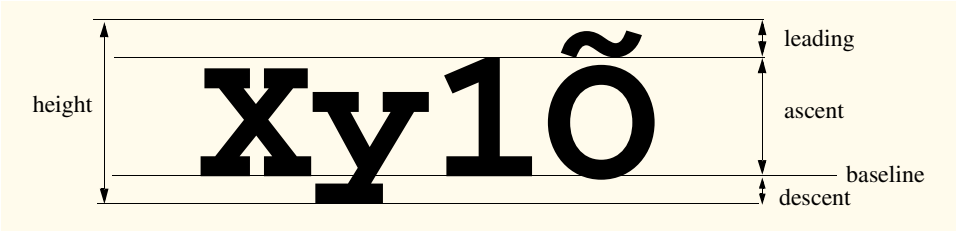

Fig. 11.10 Font metrics.

Method	Description
`public int getAscent()` `// FontMetrics class`	Returns a value representing the ascent of a font in points.
`public int getDescent()` `// FontMetrics class`	Returns a value representing the descent of a font in points.
`public int getLeading()` `// FontMetrics class`	Returns a value representing the leading of a font in points.
`public int getHeight()` `// FontMetrics class`	Returns a value representing the height of a font in points.
`public FontMetrics getFontMetrics()` `// Graphics class`	Returns the **`FontMetrics`** object for the current drawing **`Font`**.
`public FontMetrics getFontMetrics( Font f )` `// Graphics class`	Returns the **`FontMetrics`** object for the specified **`Font`** argument.

Fig. 11.11 **`FontMetrics`** and **`Graphics`** methods for obtaining font metrics.

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The program of Fig. 11.12 uses the methods of Fig. 11.11 to obtain font metric information for two fonts.

```
1  // Fig. 11.12: Metrics.java
2  // Demonstrating methods of class FontMetrics and
3  // class Graphics useful for obtaining font metrics.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class Metrics extends JFrame {
13
14    // set window's title bar String and dimensions
15    public Metrics()
16    {
17       super( "Demonstrating FontMetrics" );
18
19       setSize( 510, 210 );
20       setVisible( true );
21    }
22
23    // display font metrics
24    public void paint( Graphics g )
25    {
26       // call superclass's paint method
27       super.paint( g );
28
29       g.setFont( new Font( "SansSerif", Font.BOLD, 12 ) );
30       FontMetrics metrics = g.getFontMetrics();
31       g.drawString( "Current font: " + g.getFont(), 10, 40 );
32       g.drawString( "Ascent: " + metrics.getAscent(), 10, 55 );
33       g.drawString( "Descent: " + metrics.getDescent(), 10, 70 );
34       g.drawString( "Height: " + metrics.getHeight(), 10, 85 );
35       g.drawString( "Leading: " + metrics.getLeading(), 10, 100);
36
37       Font font = new Font( "Serif", Font.ITALIC, 14 );
38       metrics = g.getFontMetrics( font );
39       g.setFont( font );
40       g.drawString( "Current font: " + font, 10, 130 );
41       g.drawString( "Ascent: " + metrics.getAscent(), 10, 145 );
42       g.drawString( "Descent: " + metrics.getDescent(), 10, 160);
43       g.drawString( "Height: " + metrics.getHeight(), 10, 175 );
44       g.drawString( "Leading: " + metrics.getLeading(), 10, 190);
45    }
46
47    // execute application
48    public static void main( String args[] )
49    {
50       Metrics application = new Metrics();
```

Fig. 11.12 Obtaining font metric information (part 1 of 2).

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```
51
52          application.setDefaultCloseOperation(
53             JFrame.EXIT_ON_CLOSE );
54       }
55
56    }  // end class Metrics
```

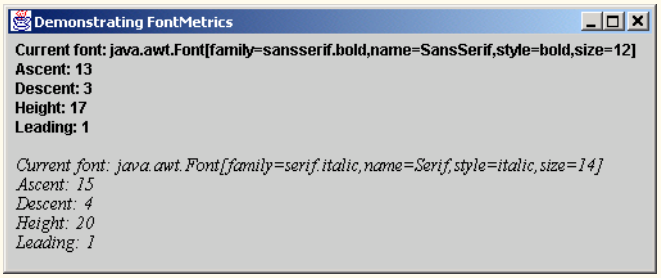

Fig. 11.12 Obtaining font metric information (part 2 of 2).

Line 29 creates and sets the current drawing font to a **SansSerif**, bold, 12-point font. Line 30 uses **Graphics** method **getFontMetrics** to obtain the **FontMetrics** object for the current font. Line 31 uses an implicit call to class **Font**'s **toString** method to output the string representation of the font. Lines 32–35 use **FontMetric** methods to obtain the ascent, descent, height and leading for the font.

Line 37 creates a new **Serif**, italic, 14-point font. Line 38 uses a second version of **Graphics** method **getFontMetrics**, which receives a **Font** argument and returns a corresponding **FontMetrics** object. Lines 41–44 obtain the ascent, descent, height and leading for the font. Notice that the font metrics are slightly different for the two fonts.

11.5 Drawing Lines, Rectangles and Ovals

This section presents a variety of **Graphics** methods for drawing lines, rectangles and ovals. The methods and their parameters are summarized in Fig. 11.13. For each drawing method that requires a **width** and **height** parameter, the **width** and **height** must be nonnegative values. Otherwise, the shape will not display..

Method	Description
`public void drawLine( int x1, int y1, int x2, int y2 )`	Draws a line between the point (**x1**, **y1**) and the point (**x2**, **y2**).
`public void drawRect( int x, int y, int width, int height )`	Draws a rectangle of the specified **width** and **height**. The top-left corner of the rectangle has the coordinates (**x**, **y**).

Fig. 11.13 **Graphics** methods that draw lines, rectangles and ovals (part 1 of 2).

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Method	Description
`public void fillRect( int x, int y, int width, int height )`	Draws a solid rectangle with the specified **width** and **height**. The top-left corner of the rectangle has the coordinate (**x**, **y**).
`public void clearRect( int x, int y, int width, int height )`	Draws a solid rectangle with the specified **width** and **height** in the current background color. The top-left corner of the rectangle has the coordinate (**x**, **y**).
`public void drawRoundRect( int x, int y, int width, int height, int arcWidth, int arcHeight )`	Draws a rectangle with rounded corners in the current color with the specified **width** and **height**. The **arcWidth** and **arcHeight** determine the rounding of the corners (see Fig. 11.15).
`public void fillRoundRect( int x, int y, int width, int height, int arcWidth, int arcHeight )`	Draws a solid rectangle with rounded corners in the current color with the specified **width** and **height**. The **arcWidth** and **arcHeight** determine the rounding of the corners (see Fig. 11.15).
`public void draw3DRect( int x, int y, int width, int height, boolean b )`	Draws a three-dimensional rectangle in the current color with the specified **width** and **height**. The top-left corner of the rectangle has the coordinates (**x**, **y**). The rectangle appears raised when b is true and is lowered when b is false.
`public void fill3DRect( int x, int y, int width, int height, boolean b )`	Draws a filled three-dimensional rectangle in the current color with the specified **width** and **height**. The top-left corner of the rectangle has the coordinates (**x**, **y**). The rectangle appears raised when b is true and is lowered when b is false.
`public void drawOval( int x, int y, int width, int height )`	Draws an oval in the current color with the specified **width** and **height**. The bounding rectangle's top-left corner is at the coordinates (**x**, **y**). The oval touches all four sides of the bounding rectangle at the center of each side (see Fig. 11.16).
`public void fillOval( int x, int y, int width, int height )`	Draws a filled oval in the current color with the specified **width** and **height**. The bounding rectangle's top-left corner is at the coordinates (**x**, **y**). The oval touches all four sides of the bounding rectangle at the center of each side (see Fig. 11.16).

Fig. 11.13 **Graphics** methods that draw lines, rectangles and ovals (part 2 of 2).

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The application of Fig. 11.14 demonstrates drawing a variety of lines, rectangles, 3D rectangles, rounded rectangles and ovals.

```
1  // Fig. 11.14: LinesRectsOvals.java
2  // Drawing lines, rectangles and ovals
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class LinesRectsOvals extends JFrame {
12
13    // set window's title bar String and dimensions
14    public LinesRectsOvals()
15    {
16       super( "Drawing lines, rectangles and ovals" );
17
18       setSize( 400, 165 );
19       setVisible( true );
20    }
21
22    // display various lines, rectangles and ovals
23    public void paint( Graphics g )
24    {
25       // call superclass's paint method
26       super.paint( g );
27
28       g.setColor( Color.red );
29       g.drawLine( 5, 30, 350, 30 );
30
31       g.setColor( Color.blue );
32       g.drawRect( 5, 40, 90, 55 );
33       g.fillRect( 100, 40, 90, 55 );
34
35       g.setColor( Color.cyan );
36       g.fillRoundRect( 195, 40, 90, 55, 50, 50 );
37       g.drawRoundRect( 290, 40, 90, 55, 20, 20 );
38
39       g.setColor( Color.yellow );
40       g.draw3DRect( 5, 100, 90, 55, true );
41       g.fill3DRect( 100, 100, 90, 55, false );
42
43       g.setColor( Color.magenta );
44       g.drawOval( 195, 100, 90, 55 );
45       g.fillOval( 290, 100, 90, 55 );
46    }
47
```

Fig. 11.14 Demonstrating **Graphics** method **drawLine** (part 1 of 2).

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```
48      // execute application
49      public static void main( String args[] )
50      {
51         LinesRectsOvals application = new LinesRectsOvals();
52
53         application.setDefaultCloseOperation(
54            JFrame.EXIT_ON_CLOSE );
55      }
56
57   }  // end class LinesRectsOvals
```

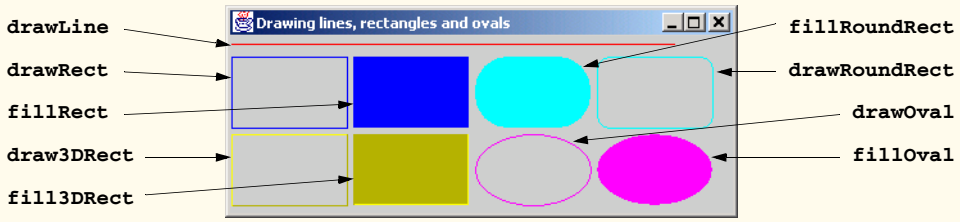

Fig. 11.14 Demonstrating **Graphics** method **drawLine** (part 2 of 2).

Methods **fillRoundRect** (line 36) and **drawRoundRect** (line 37) draw rectangles with rounded corners. Their first two arguments specify the coordinates of the upper-left corner of the *bounding rectangle*—the area in which the rounded rectangle will be drawn. Note that the upper-left corner coordinates are not the edge of the rounded rectangle, but the coordinates where the edge would be if the rectangle had square corners. The third and fourth arguments specify the **width** and **height** of the rectangle. Their last two arguments—**arcWidth** and **arcHeight**—determine the horizontal and vertical diameters of the arcs used to represent the corners.

Methods **draw3DRect** (line 40) and **fill3DRect** (line 41) take the same arguments. The first two arguments specify the top-left corner of the rectangle. The next two arguments specify the **width** and **height** of the rectangle, respectively. The last argument determines whether the rectangle is *raised* (**true**) or *lowered* (**false**). The three-dimensional effect of **draw3DRect** appears as two edges of the rectangle in the original color and two edges in a slightly darker color. The three-dimensional effect of **fill3DRect** appears as two edges of the rectangle in the original drawing color and the fill and other two edges in a slightly darker color. Raised rectangles have the original drawing color edges at the top and left of the rectangle. Lowered rectangles have the original drawing color edges at the bottom and right of the rectangle. The three-dimensional effect is difficult to see in some colors.

Figure 11.15 labels the arc width, arc height, width and height of a rounded rectangle. Using the same value for **arcWidth** and **arcHeight** produces a quarter circle at each corner. When **width**, **height**, **arcWidth** and **arcHeight** have the same values, the result is a circle. If the values for **width** and **height** are the same and the values of **arcWidth** and **arcHeight** are 0, the result is a square.

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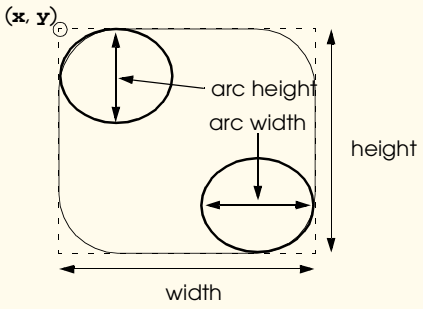

Fig. 11.15 The arc width and arc height for rounded rectangles.

The **drawOval** and **fillOval** methods take the same four arguments. The first two arguments specify the top-left coordinate of the bounding rectangle that contains the oval. The last two arguments specify the **width** and **height** of the bounding rectangle, respectively. Figure 11.16 shows an oval bounded by a rectangle. Note that the oval touches the center of all four sides of the bounding rectangle (the bounding rectangle is not displayed on the screen).

11.6 Drawing Arcs

An *arc* is a portion of a oval. Arc angles are measured in degrees. Arcs *sweep* from a *starting angle* the number of degrees specified by their *arc angle*. The starting angle indicates in degrees where the arc begins. The arc angle specifies the total number of degrees through which the arc sweeps. Figure 11.17 illustrates two arcs. The left set of axes shows an arc sweeping from zero degrees to approximately 110 degrees. Arcs that sweep in a counter-clockwise direction are measured in *positive degrees*. The right set of axes shows an arc sweeping from zero degrees to approximately –110 degrees. Arcs that sweep in a clockwise direction are measured in *negative degrees*. Notice the dashed boxes around the arcs in Fig. 11.17. When drawing an arc, we specify a bounding rectangle for an oval. The arc will sweep along part of the oval. The **Graphics** methods ***drawArc*** and ***fillArc*** for drawing arcs are summarized in Fig. 11.18.

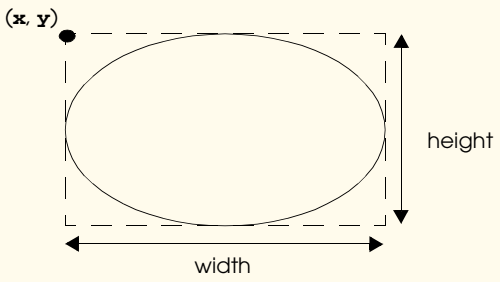

Fig. 11.16 An oval bounded by a rectangle.

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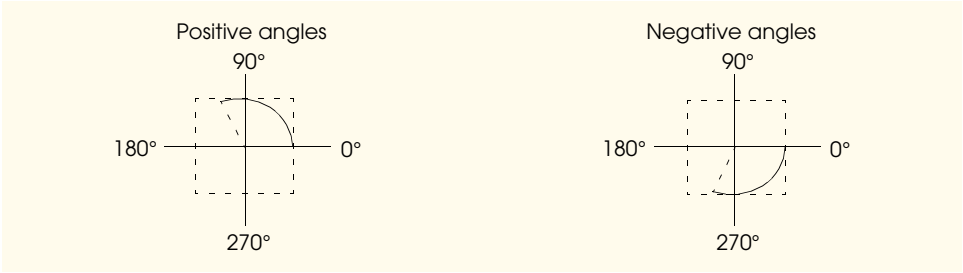

Fig. 11.17 Positive and negative arc angles.

Method	Description
`public void drawArc( int x, int y, int width, int height, int startAngle, int arcAngle )`	Draws an arc relative to the bounding rectangle's top-left coordinates *(**x**, **y**)* with the specified **width** and **height**. The arc segment is drawn starting at startAngle and sweeps arcAngle degrees.
`public void fillArc( int x, int y, int width, int height, int startAngle, int arcAngle )`	Draws a solid arc (i.e., a sector) relative to the bounding rectangle's top-left coordinates *(**x**, **y**)* with the specified **width** and **height**. The arc segment is drawn starting at startAngle and sweeps arcAngle degrees.

Fig. 11.18 **Graphics** methods for drawing arcs.

The program of Fig. 11.19 demonstrates the arc methods of Fig. 11.18. The program draws six arcs (three unfilled and three filled). To illustrate the bounding rectangle that helps determine where the arc appears, the first three arcs are displayed inside a yellow rectangle that has the same **x**, **y**, **width** and **height** arguments as the arcs.

```
1  // Fig. 11.19: DrawArcs.java
2  // Drawing arcs
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class DrawArcs extends JFrame {
12
```

Fig. 11.19 Demonstrating **drawArc** and **fillArc** (part 1 of 3).

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```
13     // set window's title bar String and dimensions
14     public DrawArcs()
15     {
16        super( "Drawing Arcs" );
17
18        setSize( 300, 170 );
19        setVisible( true );
20     }
21
22     // draw rectangles and arcs
23     public void paint( Graphics g )
24     {
25        // call superclass's paint method
26        super.paint( g );
27
28        // start at 0 and sweep 360 degrees
29        g.setColor( Color.yellow );
30        g.drawRect( 15, 35, 80, 80 );
31        g.setColor( Color.black );
32        g.drawArc( 15, 35, 80, 80, 0, 360 );
33
34        // start at 0 and sweep 110 degrees
35        g.setColor( Color.yellow );
36        g.drawRect( 100, 35, 80, 80 );
37        g.setColor( Color.black );
38        g.drawArc( 100, 35, 80, 80, 0, 110 );
39
40        // start at 0 and sweep -270 degrees
41        g.setColor( Color.yellow );
42        g.drawRect( 185, 35, 80, 80 );
43        g.setColor( Color.black );
44        g.drawArc( 185, 35, 80, 80, 0, -270 );
45
46        // start at 0 and sweep 360 degrees
47        g.fillArc( 15, 120, 80, 40, 0, 360 );
48
49        // start at 270 and sweep -90 degrees
50        g.fillArc( 100, 120, 80, 40, 270, -90 );
51
52        // start at 0 and sweep -270 degrees
53        g.fillArc( 185, 120, 80, 40, 0, -270 );
54     }
55
56     // execute application
57     public static void main( String args[] )
58     {
59        DrawArcs application = new DrawArcs();
60
61        application.setDefaultCloseOperation(
62           JFrame.EXIT_ON_CLOSE );
63     }
64
65  }  // end class DrawArcs
```

Fig. 11.19 Demonstrating **drawArc** and **fillArc** (part 2 of 3).

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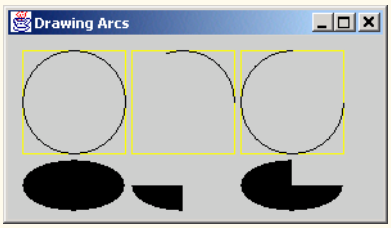

Fig. 11.19 Demonstrating **drawArc** and **fillArc** (part 3 of 3).

11.7 Drawing Polygons and Polylines

Polygons are multisided shapes. *Polylines* are a series of connected points. Graphics methods for drawing polygons and polylines are discussed in Fig. 11.20. Note that some methods require a ***Polygon*** object (package **java.awt**). Class **Polygon**'s constructors are also described in Fig. 11.20.

Method	Description
`public void drawPolygon( int xPoints[], int yPoints], int points )`	Draws a polygon. The *x*-coordinate of each point is specified in the **xPoints** array and the *y*-coordinate of each point is specified in the **yPoints** array. The last argument specifies the number of **points**. This method draws a closed polygon—even if the last point is different from the first point.
`public void drawPolyline( int xPoints[], int yPoints[], int points )`	Draws a series of connected lines. The *x*-coordinate of each point is specified in the **xPoints** array and the *y*-coordinate of each point is specified in the **yPoints** array. The last argument specifies the number of **points**. If the last point is different from the first point, the polyline is not closed.
`public void drawPolygon( Polygon p )`	Draws the specified closed polygon.
`public void fillPolygon( int xPoints[], int yPoints[], int points )`	Draws a solid polygon. The *x*-coordinate of each point is specified in the **xPoints** array and the *y*-coordinate of each point is specified in the **yPoints** array. The last argument specifies the number of **points**. This method draws a closed polygon—even if the last point is different from the first point.
`public void fillPolygon( Polygon p )`	Draws the specified solid polygon. The polygon is closed.

Fig. 11.20 **Graphics** methods for drawing polygons and class **Polygon** constructors (part 1 of 2).

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Method	Description
`public Polygon()` // Polygon class	Constructs a new polygon object. The polygon does not contain any points.
`public Polygon( int xValues[], int yValues[], int numberOfPoints )` // Polygon class	Constructs a new polygon object. The polygon has **`numberOfPoints`** sides, with each point consisting of an *x*-coordinate from **`xValues`** and a *y*-coordinate from **`yValues`**.

Fig. 11.20 **`Graphics`** methods for drawing polygons and class **`Polygon`** constructors (part 2 of 2).

The program of Fig. 11.21 draws polygons and polylines, using the methods and constructors in Fig. 11.20.

```
1  // Fig. 11.21: DrawPolygons.java
2  // Drawing polygons
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class DrawPolygons extends JFrame {
12
13    // set window's title bar String and dimensions
14    public DrawPolygons()
15    {
16       super( "Drawing Polygons" );
17
18       setSize( 275, 230 );
19       setVisible( true );
20    }
21
22    // draw polygons and polylines
23    public void paint( Graphics g )
24    {
25       // call superclass's paint method
26       super.paint( g );
27
28       int xValues[] = { 20, 40, 50, 30, 20, 15 };
29       int yValues[] = { 50, 50, 60, 80, 80, 60 };
30       Polygon polygon1 = new Polygon( xValues, yValues, 6 );
31
32       g.drawPolygon( polygon1 );
```

Fig. 11.21 Demonstrating **`drawPolygon`** and **`fillPolygon`**.

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```
33
34          int xValues2[] = { 70, 90, 100, 80, 70, 65, 60 };
35          int yValues2[] = { 100, 100, 110, 110, 130, 110, 90 };
36
37          g.drawPolyline( xValues2, yValues2, 7 );
38
39          int xValues3[] = { 120, 140, 150, 190 };
40          int yValues3[] = { 40, 70, 80, 60 };
41
42          g.fillPolygon( xValues3, yValues3, 4 );
43
44          Polygon polygon2 = new Polygon();
45          polygon2.addPoint( 165, 135 );
46          polygon2.addPoint( 175, 150 );
47          polygon2.addPoint( 270, 200 );
48          polygon2.addPoint( 200, 220 );
49          polygon2.addPoint( 130, 180 );
50
51          g.fillPolygon( polygon2 );
52       }
53
54       // execute application
55       public static void main( String args[] )
56       {
57          DrawPolygons application = new DrawPolygons();
58
59          application.setDefaultCloseOperation(
60             JFrame.EXIT_ON_CLOSE );
61       }
62
63    }  // end class DrawPloygons
```

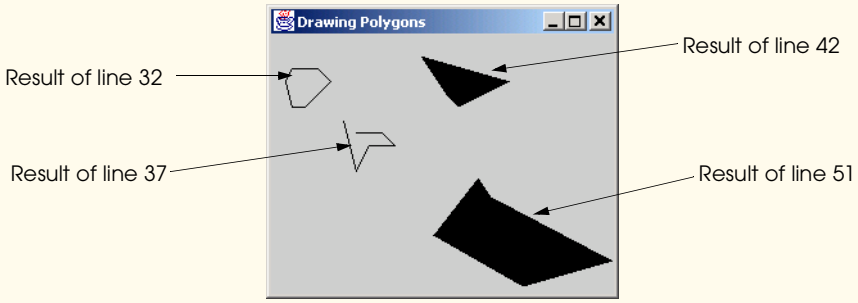

Fig. 11.21 Demonstrating **drawPolygon** and **fillPolygon**.

Lines 28–29 create two **int** arrays and use them to specify the points for **Polygon polygon1**. The **Polygon** constructor call at line 30 receives array **xValues**, which contains the *x*-coordinate of each point, array **yValues**, which contains the *y*-coordinate of each point, and 6 (the number of points in the polygon). Line 32 displays **polygon1** by passing it as an argument to **Graphics** method **drawPolygon**.

Lines 34–35 create two **int** arrays and use them to specify the points for a series of connected lines. Array **xValues2** contains the *x*-coordinate of each point and array

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yValues2 contains the *y*-coordinate of each point. Line 37 uses **Graphics** method **drawPolyline** to display the series of connected lines specified with the arguments **xValues2**, **yValues2** and **7** (the number of points).

Lines 39–40 create two **int** arrays and use them to specify the points of a polygon. Array **xValues3** contains the *x*-coordinate of each point and array **yValues3** contains the *y*-coordinate of each point. Line 42 displays a polygon by passing to **Graphics** method **fillPolygon** the two arrays (**xValues3** and **yValues3**) and the number of points to draw (**4**).

Common Programming Error 11.3

*An **ArrayIndexOutOfBoundsException** is thrown if the number of points specified in the third argument to method **drawPolygon** or method **fillPolygon** is greater than the number of elements in the arrays of coordinates that define the polygon to display.*

Line 44 creates **Polygon polygon2** with no points. Lines 45–49 use **Polygon** method ***addPoint*** to add pairs of *x*- and *y*-coordinates to the **Polygon**. Line 51 displays **Polygon polygon2** by passing it to **Graphics** method **fillPolygon**.

11.8 The Java2D API

The new *Java2D API* provides advanced two-dimensional graphics capabilities for programmers who require detailed and complex graphical manipulations. The API includes features for processing line art, text and images in packages **java.awt**, **java.awt.image**, **java.awt.color**, **java.awt.font**, **java.awt.geom**, **java.awt.print** and **java.awt.image.renderable**. The capabilities of the API are far too broad to cover in this textbook. For an overview of the capabilities, see the Java2D demo (demonstrated in Chapter 3). In this section, we present an overview of several Java2D capabilities.

Drawing with the Java2D API is accomplished with an instance of class ***Graphics2D*** (package **java.awt**). Class **Graphics2D** is a subclass of class **Graphics**, so it has all the graphics capabilities demonstrated earlier in this chapter. In fact, the actual object we have used to draw in every **paint** method is a **Graphics2D** object that is passed to method **paint** and accessed via the superclass **Graphics** reference **g**. To access the **Graphics2D** capabilities, we must downcast the **Graphics** reference passed to **paint** to a **Graphics2D** reference with a statement such as

```
Graphics2D g2d = ( Graphics2D ) g;
```

The programs of the next several sections use this technique.

11.9 Java2D Shapes

Next, we present several Java2D shapes from package **java.awt.geom**, including ***Ellipse2D.Double***, ***Rectangle2D.Double***, ***RoundRectangle2D.Double***, ***Arc2D.Double*** and ***Line2D.Double***. Note the syntax of each class name. Each of these classes represents a shape with dimensions specified as double-precision floating-point values. There is a separate version of each represented with single-precision floating-point values (such as ***Ellipse2D.Float***). In each case, **Double** is a **static** inner class of the class to the left of the dot operator (e.g., **Ellipse2D**). To use the **static** inner class, we simply qualify its name with the outer class name.

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The program of Fig. 11.22 demonstrates several Java2D shapes and drawing characteristics, such as thickening lines, filling shapes with patterns and drawing dashed lines. These are just a few of the many capabilities provided by Java2D.

```
1  // Fig. 11.22: Shapes.java
2  // Demonstrating some Java2D shapes
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.awt.geom.*;
8  import java.awt.image.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class Shapes extends JFrame {
14
15    // set window's title bar String and dimensions
16    public Shapes()
17    {
18       super( "Drawing 2D shapes" );
19
20       setSize( 425, 160 );
21       setVisible( true );
22    }
23
24    // draw shapes with Java2D API
25    public void paint( Graphics g )
26    {
27       // call superclass's paint method
28       super.paint( g );
29
30       // create 2D by casting g to Graphics2D
31       Graphics2D g2d = ( Graphics2D ) g;
32
33       // draw 2D ellipse filled with a blue-yellow gradient
34       g2d.setPaint( new GradientPaint( 5, 30, Color.blue, 35,
35          100, Color.yellow, true ) );
36       g2d.fill( new Ellipse2D.Double( 5, 30, 65, 100 ) );
37
38       // draw 2D rectangle in red
39       g2d.setPaint( Color.red );
40       g2d.setStroke( new BasicStroke( 10.0f ) );
41       g2d.draw( new Rectangle2D.Double( 80, 30, 65, 100 ) );
42
43       // draw 2D rounded rectangle with a buffered background
44       BufferedImage buffImage = new BufferedImage(
45          10, 10, BufferedImage.TYPE_INT_RGB );
46
47       Graphics2D gg = buffImage.createGraphics();
48       gg.setColor( Color.yellow ); // draw in yellow
```

Fig. 11.22 Demonstrating some Java2D shapes.

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```
49          gg.fillRect( 0, 0, 10, 10 ); // draw a filled rectangle
50          gg.setColor( Color.black );  // draw in black
51          gg.drawRect( 1, 1, 6, 6 );   // draw a rectangle
52          gg.setColor( Color.blue );   // draw in blue
53          gg.fillRect( 1, 1, 3, 3 );   // draw a filled rectangle
54          gg.setColor( Color.red );    // draw in red
55          gg.fillRect( 4, 4, 3, 3 );   // draw a filled rectangle
56
57          // paint buffImage onto the JFrame
58          g2d.setPaint( new TexturePaint(
59             buffImage, new Rectangle( 10, 10 ) ) );
60          g2d.fill( new RoundRectangle2D.Double(
61             155, 30, 75, 100, 50, 50 ) );
62
63          // draw 2D pie-shaped arc in white
64          g2d.setPaint( Color.white );
65          g2d.setStroke( new BasicStroke( 6.0f ) );
66          g2d.draw( new Arc2D.Double(
67             240, 30, 75, 100, 0, 270, Arc2D.PIE ) );
68
69          // draw 2D lines in green and yellow
70          g2d.setPaint( Color.green );
71          g2d.draw( new Line2D.Double( 395, 30, 320, 150 ) );
72
73          float dashes[] = { 10 };
74
75          g2d.setPaint( Color.yellow );
76          g2d.setStroke( new BasicStroke( 4, BasicStroke.CAP_ROUND,
77             BasicStroke.JOIN_ROUND, 10, dashes, 0 ) );
78          g2d.draw( new Line2D.Double( 320, 30, 395, 150 ) );
79       }
80
81       // execute application
82       public static void main( String args[] )
83       {
84          Shapes application = new Shapes();
85
86          application.setDefaultCloseOperation(
87             JFrame.EXIT_ON_CLOSE );
88       }
89
90    }  // end class Shapes
```

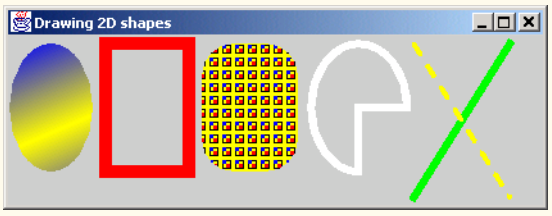

Fig. 11.22 Demonstrating some Java2D shapes.

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Line 31 casts the **Graphics** reference received by **paint** to a **Graphics2D** reference and assigns it to **g2d** to allow access to the **Java2D** features.

The first shape we draw is an oval filled with gradually changing colors. Lines 34–35 invoke **Graphics2D** method ***setPaint*** to set the ***Paint*** object that determines the color for the shape to display. A **Paint** object is an object of any class that implements interface **java.awt.Paint**. The **Paint** object can be something as simple as one of the predefined **Color** objects introduced in Section 11.3 (class **Color** implements **Paint**), or the **Paint** object can be an instance of the Java2D API's ***GradientPaint***, ***SystemColor*** or ***TexturePaint*** classes. In this case, we use a **GradientPaint** object.

Class **GradientPaint** helps draw a shape in a gradually changing colors—called a *gradient*. The **GradientPaint** constructor used here requires seven arguments. The first two arguments specify the starting coordinate for the gradient. The third argument specifies the starting **Color** for the gradient. The fourth and fifth arguments specify the ending coordinate for the gradient. The sixth argument specifies the ending **Color** for the gradient. The last argument specifies if the gradient is cyclic (**true**) or acyclic (**false**). The two coordinates determine the direction of the gradient. Because the second coordinate *(35, 100)* is down and to the right of the first coordinate *(5, 30)*, the gradient goes down and to the right at an angle. Because this gradient is cyclic (**true**), the color starts with blue, gradually becomes yellow, then gradually returns to blue. If the gradient is acyclic, the color transitions from the first color specified (e.g., blue) to the second color (e.g., yellow).

Line 36 uses **Graphics2D** method ***fill*** to draw a filled ***Shape*** object. The **Shape** object is an instance of any class that implements interface **Shape** (package **java.awt**)—in this case, an instance of class **Ellipse2D.Double**. The **Ellipse2D.Double** constructor receives four arguments specifying the bounding rectangle for the ellipse to display.

Next we draw a red rectangle with a thick border. Line 39 uses **setPaint** to set the **Paint** object to **Color.red**. Line 40 uses **Graphics2D** method ***setStroke*** to set the characteristics of the rectangle's border (or the lines for any other shape). Method **setStroke** requires a ***Stroke*** object as its argument. The **Stroke** object is an instance of any class that implements interface **Stroke** (package **java.awt**)—in this case, an instance of class ***BasicStroke***. Class **BasicStroke** provides a variety of constructors to specify the width of the line, how the line ends (called the *end caps*), how lines join together (called *line joins*) and the dash attributes of the line (if it is a dashed line). The constructor here specifies that the line should be 10 pixels wide.

Line 41uses **Graphics2D** method ***draw*** to draw a ***Shape*** object—in this case, an instance of class **Rectangle2D.Double**. The **Rectangle2D.Double** constructor receives four arguments specifying the upper-left *x*-coordinate, upper-left *y*-coordinate, width and height of the rectangle.

Next we draw a rounded rectangle filled with a pattern created in a ***BufferedImage*** (package **java.awt.image**) object. Lines 44–45 create the **BufferedImage** object. Class **BufferedImage** can be used to produce images in color and gray scale. This particular **BufferedImage** is 10 pixels wide and 10 pixels tall. The third constructor argument **BufferedImage.TYPE_INT_RGB** indicates that the image is stored in color using the RGB color scheme.

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To create the fill pattern for the rounded rectangle, we must first draw into the **BufferedImage**. Line 47 creates a **Graphics2D** object that can be used to draw into the **BufferedImage**. Lines 48–55 use methods **setColor**, **fillRect** and **drawRect** (discussed earlier in this chapter) to create the pattern.

Lines 58–59 set the **Paint** object to a new **TexturePaint** (package **java.awt**) object. A **TexturePaint** object uses the image stored in its associated **BufferedImage** as the fill texture for a filled-in shape. The second argument specifies the **Rectangle** area from the **BufferedImage** that will be replicated through the texture. In this case, the **Rectangle** is the same size as the **BufferedImage**. However, a smaller portion of the **BufferedImage** can be used.

Lines 60–61use **Graphics2D** method **fill** to draw a filled **Shape** object—in this case, an instance of class ***RoundRectangle2D.Double***. The constructor for class **RoundRectangle2D.Double** receives six arguments specifying the rectangle dimensions and the arc width and arc height used to determine the rounding of the corners.

Next we draw a pie-shaped arc with a thick white line. Line 64 sets the **Paint** object to **Color.white**. Line 65 sets the **Stroke** object to a new **BasicStroke** for a line 6 pixels wide. Lines 66–67 use **Graphics2D** method **draw** to draw a **Shape** object—in this case, an **Arc2D.Double**. The **Arc2D.Double** constructor's first four arguments specifying the upper-left *x*-coordinate, upper-left *y*-coordinate, width and height of the bounding rectangle for the arc. The fifth argument specifies the start angle. The sixth argument specifies the arc angle. The last argument specifies the how the arc is closed. Constant ***Arc2D.PIE*** indicates that the arc is closed by drawing two lines. One line from the arc's starting point to the center of the bounding rectangle and one line from the center of the bounding rectangle to the ending point. Class **Arc2D** provides two other **static** constants for specifying how the arc is closed. Constant ***Arc2D.CHORD*** draws a line from the starting point to the ending point. Constant ***Arc2D.OPEN*** specifies that the arc is not closed.

Finally, we draw two lines using ***Line2D*** objects—one solid and one dashed. Line 70 sets the **Paint** object to **Color.green**. Line 71 uses **Graphics2D** method **draw** to draw a **Shape** object—in this case, an instance of class **Line2D.Double**. The **Line2D.Double** constructor's arguments specify starting coordinates and ending coordinates of the line.

Line 73 defines a one-element **float** array containing the value 10. This array will be used to describe the dashes in the dashed line. In this case, each dash will be 10 pixels long. To create dashes of different lengths in a pattern, simply provide the lengths of each dash as an element in the array. Line 75 sets the **Paint** object to **Color.yellow**. Lines 76–77 set the **Stroke** object to a new **BasicStroke**. The line will be **4** pixels wide and will have rounded ends (**BasicStroke.CAP_ROUND**). If lines join together (as in a rectangle at the corners), the joining of the lines will be rounded (**BasicStroke.JOIN_ROUND**). The **dashes** argument specifies the dash lengths for the line. The last argument indicates the starting subscript in the **dashes** array for the first dash in the pattern. Line 78 then draws a line with the current **Stroke**.

Next we present a general path—a shape constructed from straight lines and complex curves. A general path is represented with an object of class ***GeneralPath*** (package **java.awt.geom**). The program of Fig. 11.23 demonstrates drawing a general path in the shape of a five-pointed star.

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```
1  // Fig. 11.23: Shapes2.java
2  // Demonstrating a general path
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.awt.geom.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class Shapes2 extends JFrame {
13
14    // set window's title bar String, background color
15    // and dimensions
16    public Shapes2()
17    {
18       super( "Drawing 2D Shapes" );
19
20       getContentPane().setBackground( Color.yellow );
21       setSize( 400, 400 );
22       setVisible( true );
23    }
24
25    // draw general paths
26    public void paint( Graphics g )
27    {
28       // call superclass's paint method
29       super.paint( g );
30
31       int xPoints[] =
32          { 55, 67, 109, 73, 83, 55, 27, 37, 1, 43 };
33       int yPoints[] =
34          { 0, 36, 36, 54, 96, 72, 96, 54, 36, 36 };
35
36       Graphics2D g2d = ( Graphics2D ) g;
37
38       // create a star from a series of points
39       GeneralPath star = new GeneralPath();
40
41       // set the initial coordinate of the General Path
42       star.moveTo( xPoints[ 0 ], yPoints[ 0 ] );
43
44       // create the star--this does not draw the star
45       for ( int count = 1; count < xPoints.length; count++ )
46          star.lineTo( xPoints[ count ], yPoints[ count ] );
47
48       // close the shape
49       star.closePath();
50
51       // translate the origin to (200, 200)
52       g2d.translate( 200, 200 );
```

Fig. 11.23 Demonstrating some Java2D shapes

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```
53
54          // rotate around origin and draw stars in random colors
55          for ( int count = 1; count <= 20; count++ ) {
56
57             // rotate coordinate system
58             g2d.rotate( Math.PI / 10.0 );
59
60             // set random drawing color
61             g2d.setColor( new Color(
62                ( int ) ( Math.random() * 256 ),
63                ( int ) ( Math.random() * 256 ),
64                ( int ) ( Math.random() * 256 ) ) );
65
66             // draw filled star
67             g2d.fill( star );
68          }
69
70       }  // end method paint
71
72       // execute application
73       public static void main( String args[] )
74       {
75          Shapes2 application = new Shapes2();
76
77          application.setDefaultCloseOperation(
78             JFrame.EXIT_ON_CLOSE );
79       }
80
81    }  // end class Shapes2
```

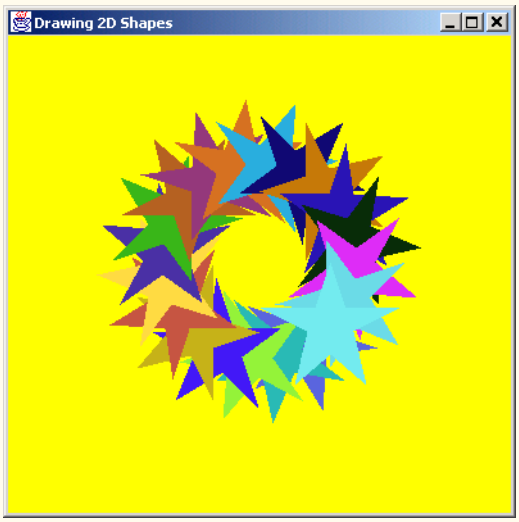

Fig. 11.23 Demonstrating some Java2D shapes

Lines 31–34 define two **int** arrays representing the *x*- and *y*-coordinates of the points in the star. Line 39 defines **GeneralPath** object **star**.

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Line 42 uses **GeneralPath** method ***moveTo*** to specify the first point in the **star**. The **for** structure at lines 45–46 use **GeneralPath** method ***lineTo*** to draw a line to the next point in the **star**. Each new call to **lineTo** draws a line from the previous point to the current point. Line 49 uses **GeneralPath** method ***closePath*** to draw a line from the last point to the point specified in the last call to **moveTo**. This completes the general path.

Line 52 uses **Graphics2D** method ***translate*** to move the drawing origin to location *(200, 200)*. All drawing operations now use location *(200, 200)* as *(0, 0)*.

The **for** structure at line 55–68 draws the **star** 20 times by rotating it around the new origin point. Line 58 uses **Graphics2D** method ***rotate*** to rotate the next displayed shape. The argument specifies the rotation angle in radians (with 360° = 2π radians). Line 67 uses **Graphics2D** method **fill** to draw a filled version of the **star**.

11.10 (Optional Case Study) Thinking About Objects: Designing Interfaces with the UML

In Section 10.22, we incorporated event handling into our simulation by modifying the collaboration diagram that deals with passengers entering and exiting the elevator. We included both event handling and inheritance in that diagram. The **Elevator** informs its **Door** of the **Elevator**'s arrival. This **Door** opens the arrival **Floor**'s **Door** by obtaining its handle through a **Location** object (which was included in the arrival event), and potentially two **Person** objects exit and enter the **Elevator** after both **Door**s open. We also discussed listener interfaces. In this section, we represent our listener interface with the UML.

Realizations

The UML expresses the relationship between a class and an interface through a *realization*. A class *realizes*, or implements, the behaviors of an interface. A class diagram can show a realization between classes and interfaces. As mentioned in "Thinking About Objects" Section 3.8, the UML provides two notations to draw a class diagram—the complete diagram and the elided (condensed) diagram. Figure 11.24 shows the complete class diagram that models the realization between class **Person** and interface **DoorListener**. The diagram is similar to the generalization diagram, except that the arrow expressing the relationship is dashed instead of solid. Note that the middle compartment in interface **DoorListener** is empty, because interfaces do not contain variables—interfaces can contain constants, but interface **DoorListener** does not contain any constants. Lastly, note the word **interface** placed in guillemets (« ») located in the first compartment of interface **DoorListener**. This notation distinguishes interface **DoorListener** as an interface in our system. Items placed in guillemets are called *stereotypes* in the UML. A stereotype indicates an element's role—or purpose—in a UML diagram.

Figure 11.25 shows the alternate way to represent the realization of class **Person** and interface **DoorListener** in the UML. Figure 11.25 is the elided diagram of Fig. 11.24. The small circle represents the interface, and the solid line represents the realization. By hiding its operations, we condense the interface, making it easier to read; however, in doing so, we sacrifice the information about its behaviors. When constructing an elided diagram, common practice is to place the information regarding any behavior in a separate diagram—for example, we place the full **DoorListener** class in the class diagram of Fig. 11.28.

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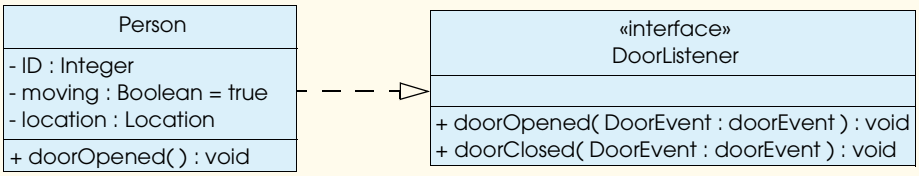

Fig. 11.24 Class diagram that models class **`Person`** realizing interface **`DoorListener`**.

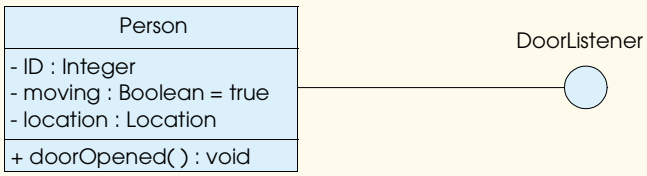

Fig. 11.25 Elided class diagram that models class **`Person`** realizing interface **`DoorListener`**.

Forward engineering from the UML to implemented Java code benefits from well-constructed realization diagrams. When declaring any class, specify the realization between that class and its interface—that class will "implement" the interface and override the interface's methods. For example, we use Fig. 11.24 to begin constructing **`Person.java`**:

```
public class Person implements DoorListener {

   // constructor
   public Person() {}

   // methods of DoorListener
   public void doorOpened( DoorEvent doorEvent ) {}
   public void doorClosed( DoorEvent doorEvent ) {}
}
```

Figure 11.26 shows the Java complete implementation for Fig. 11.24. Lines 6–8 and lines 14–15 include the attributes and operations of **`Person`**, respectively—in this case, the **`doorOpened`** operation (line 14) was already included when we implemented the **`DoorListener`** interface, so we include only the attributes of **`Person`**:

```
1  // Person.java
2  // Generated from Fig. 11.24
3  public class Person implements DoorListener {
```

Fig. 11.26 Class **`Person`** is generated from Fig. 11.24 (part 1 of 2).

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```
4
5      // attributes
6      private int ID;
7      private boolean moving = true;
8      private Location location;
9
10     // constructor
11     public Person() {}
12
13     // methods of DoorListener
14     public void doorOpened( DoorEvent doorEvent ) {}
15     public void doorClosed( DoorEvent doorEvent ) {}
16  }
```

Fig. 11.26 Class **Person** is generated from Fig. 11.24 (part 2 of 2).

When a **Door** opens or closes, that **Door** invokes only those methods declared in interface **DoorListener**, but only if the **Person** has registered with that **Door** to receive **DoorEvent**s. Finally, we present the elided class diagram that models the realizations in our elevator model in Fig. 11.27—the elided diagram does not contain any interface methods (making the diagram easier to read), so we present the class diagram for interfaces in Fig. 11.28, which shows all interface methods. Refer to these diagrams when studying the elevator simulation implementation in Appendices G, H and I.

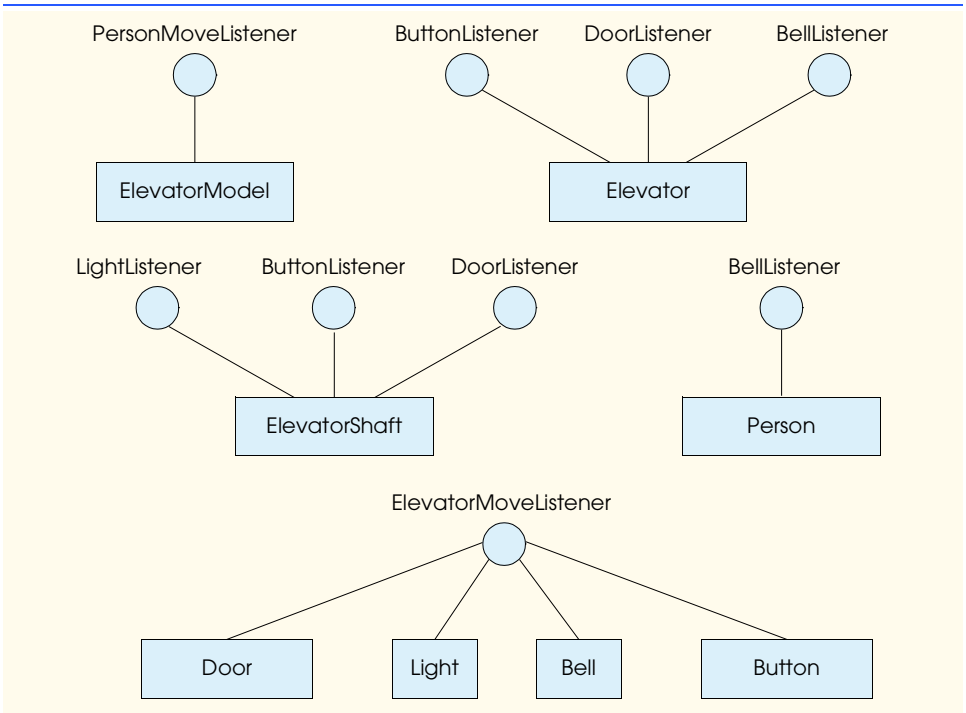

Fig. 11.27 Class diagram that models realizations in the elevator model.

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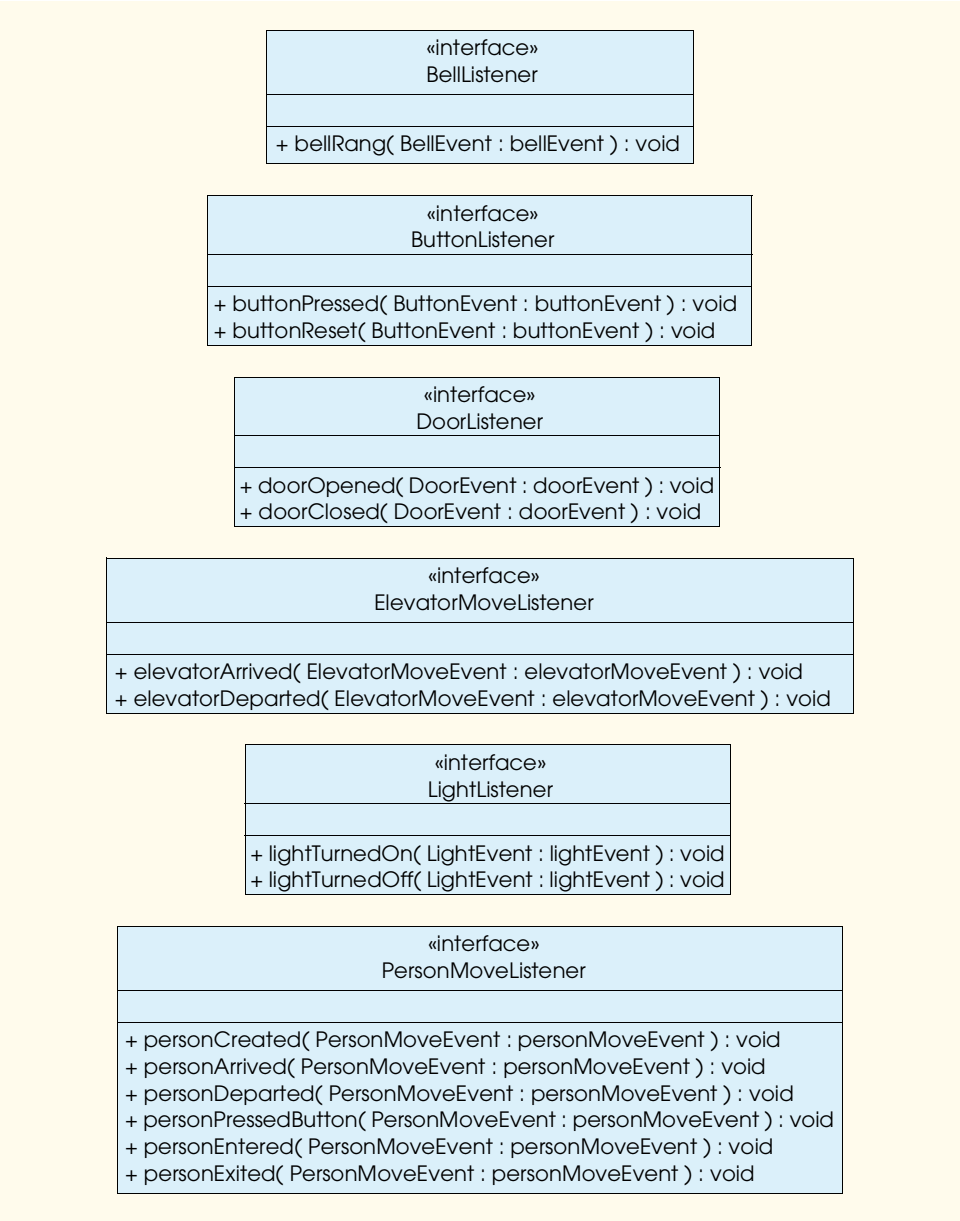

Fig. 11.28 Class diagram for listener interfaces.

According to Fig. 11.27, classes **`Door`**, **`Light`**, **`Bell`** and **`Button`** implement interface **`ElevatorMoveListener`**. Class **`Elevator`** implements interfaces **`ButtonListener`**, **`DoorListener`** and **`BellListener`**. Class **`ElevatorModel`** implements interface **`PersonMoveListener`**. Class **`ElevatorShaft`** implements interfaces **`LightListener`**, **`ButtonListener`** and **`DoorListener`**. Lastly, class

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Person implements interface **DoorListener**. We reexamine Fig. 11.27 in Appendix H when we begin coding our model.

In this section we showed how to represent interfaces and realizations with the UML. We also presented class diagrams showing the listener interfaces and their realizations for our elevator simulation. In "Thinking About Objects" Section 12.16, we model how the user interacts with our simulation.

SUMMARY

- A coordinate system is a scheme for identifying every possible point on the screen.
- The upper-left corner of a GUI component has the coordinates *(0, 0)*. A coordinate pair is composed of an x-coordinate (the horizontal coordinate) and a y-coordinate (the vertical coordinate).
- Coordinate units are measured in pixels. A pixel is a display monitor's smallest unit of resolution.
- A graphics context enables drawing on the screen in Java. A Graphics object manages a graphics context by controlling how information is drawn.
- **Graphics** objects contain methods for drawing, font manipulation, color manipulation and so on.
- Method **paint** is normally called in response to an *event*, such as uncovering a window.
- Method **repaint** requests a call to **Component** method **update** as soon as possible to clear the **Component**'s background of any previous drawing, then **update** calls **paint** directly.
- Class **Color** defines methods and constants for manipulating colors in a Java program.
- Java uses RGB colors in which the red, green and blue color components are integers in the range from 0 to 255 or floating-point values in the range from 0.0 to 1.0. The larger the RGB value, the greater the amount of that particular color.
- **Color** methods **getRed**, **getGreen** and **getBlue** return integer values from 0 to 255 representing the amount of red, green and blue in a **Color**.
- Class **Color** provides 13 predefined **Color** objects.
- **Graphics** method getColor returns a **Color** object representing the current drawing color. **Graphics** method setColor sets the current drawing color.
- Java provides class **JColorChooser** to display a dialog for selecting colors.
- **static** method **showDialog** of class **JColorChooser** displays a color chooser dialog. This method returns the selected **Color** object (**null**, if none is selected).
- The default **JColorChooser** dialog allows you to select a color from a variety of color swatches. The **HSB** tab allows you to select a color based on hue, saturation and brightness. The **RGB** tab allows you to select a color by using sliders for the red, green and blue components of the color.
- **Component** method **setBackground** (one of the many **Component** methods that can be used on most GUI components) changes the background color of a component.
- Class **Font**'s constructor takes three arguments—the font name, the font style and the font size. The font name is any font currently supported by the system. The font style is **Font.PLAIN**, **Font.ITALIC** or **Font.BOLD**. The font size is measured in points.
- **Graphics** method **setFont** sets the drawing font.
- Class **FontMetrics** defines several methods for obtaining font metrics.
- **Graphics** method **getFontMetrics** with no arguments obtains the **FontMetrics** object for the current font. **Graphics** method **getFontMetrics** that receives a **Font** argument returns a corresponding **FontMetrics** object.

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- Methods **draw3DRect** and **fill3DRect** take five arguments specifying the top-left corner of the rectangle, the **width** and **height** of the rectangle and whether the rectangle is raised (**true**) or lowered (**false**).
- Methods **drawRoundRect** and **fillRoundRect** draw rectangles with rounded corners. Their first two arguments specify the upper-left corner, the third and fourth arguments specify the **width** and **height**, and the last two arguments—**arcWidth** and **arcHeight**—determine the horizontal and vertical diameters of the arcs used to represent the corners.
- Methods **drawOval** and **fillOval** take the same arguments—the top-left coordinate and the **width** and the **height** of the bounding rectangle that contains the oval.
- An arc is a portion of an oval. Arcs sweep from a starting angle the number of degrees specified by their arc angle. The starting angle specifies where the arc begins and the arc angle specifies the total number of degrees through which the arc sweeps. Arcs that sweep counterclockwise are measured in positive degrees and arcs that sweep clockwise are measured in negative degrees.
- Methods **drawArc** and **fillArc** take the same arguments—the top-left coordinate, the **width** and the **height** of the bounding rectangle that contains the arc and the **startAngle** and **arcAngle** that define the sweep of the arc.
- Polygons are multisided shapes. Polylines are a series of connected points.
- One **Polygon** constructor receives an array containing the *x*-coordinate of each point, an array containing the *y*-coordinate of each point and the number of points in the polygon.
- One version of **Graphics** method **drawPolygon** displays a **Polygon** object. Another version receives an array containing the x-coordinate of each point, an array containing the y-coordinate of each point and the number of points in the polygon and displays the corresponding polygon.
- **Graphics** method **drawPolyline** displays a series of connected lines specified by its arguments (an array containing the x-coordinate of each point, an array containing the y-coordinate of each point and the number of points).
- **Polygon** method **addPoint** adds pairs of x- and y-coordinates to a **Polygon**.
- The Java2D API provides advanced two-dimensional graphics capabilities for processing line art, text and images.
- To access the **Graphics2D** capabilities, downcast the **Graphics** reference passed to **paint** to a **Graphics2d** reference.
- **Graphics2D** method **setPaint** sets the **Paint** object that determines the color and texture for the shape to display. A **Paint** object is an object of any class that implements interface **java.awt.Paint**. The **Paint** object can be a **Color** or an instance of the Java2D API's **GradientPaint**, **SystemColor** or **TexturePaint** classes.
- Class **GradientPaint** draws a shape in a gradually changing color called a gradient.
- **Graphics2D** method **fill** draws a filled **Shape** object. The **Shape** object is an instance of any class that implements interface **Shape**.
- The **Ellipse2D.Double** constructor receives four arguments specifying the bounding rectangle for the ellipse to display.
- **Graphics2D** method **setStroke** sets the characteristics of the lines used to draw a shape. Method **setStroke** requires a **Stroke** object as its argument. The **Stroke** object is an instance of any class that implements interface **Stroke**, such as a **BasicStroke**.
- **Graphics2D** method **draw** draws a **Shape** object. The **Shape** object is an instance of any class that implements interface **Shape**.
- The **Rectangle2D.Double** constructor receives four arguments specifying the upper-left *x*-coordinate, upper-left *y*-coordinate, width and height of the rectangle.

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- Class **BufferedImage** can be used to produce images in color and gray scale.
- A **TexturePaint** object uses the image stored in its associated **BufferedImage** as the fill texture for a filled-in shape.
- The **RoundRectangle2D.Double** constructor receives six arguments specifying the rectangle's dimensions and the arc width and arc height used to determine the rounding of the corners.
- The **Arc2D.Double** constructor's first four arguments specify the upper-left *x*-coordinate, upper-left *y*-coordinate, width and height of the bounding rectangle for the arc. The fifth argument specifies the start angle. The sixth argument specifies the end angle. The last argument specifies the type of arc (**Arc2D.PIE**, **Arc2D.CHORD** or **Arc2D.OPEN**).
- The **Line2D.Double** constructor's arguments specify starting and ending line coordinates.
- A general path is a shape constructed from straight lines and complex curves represented with an object of class **GeneralPath** (package **java.awt.geom**).
- **GeneralPath** method **moveTo** specifies the first point in a general path. **GeneralPath** method **lineTo** draws a line to the next point in the general path. Each new call to **lineTo** draws a line from the previous point to the current point. **GeneralPath** method **closePath** draws a line from the last point to the point specified in the last call to **moveTo**.
- **Graphics2D** method **translate** moves the drawing origin to a new location. All drawing operations now use that location as *(0, 0)*.
- **Graphics2D** method **rotate** to rotate the next that is displayed. Its argument specifies the rotation angle in radians (with 360° = 2π radians).

TERMINOLOGY

addPoint method
angle
arc bounded by a rectangle
arc height
arc sweeping through an angle
arc width
Arc2D.Double class
ascent
background color
baseline
bounding rectangle
BufferedImage class
closed polygon
closePath method
Color class
Component class
coordinate
coordinate system
degree
descent
draw an arc
draw method
draw3DRect method
drawArc method
drawLine method
drawOval method
drawPolygon method
drawPolyline method
drawRect method
drawRoundRect method
Ellipse2D.Double class
event
event-driven process
fill method
fill3DRect method
fillArc method
filled polygon
fillOval method
fillPolygon method
fillRect method
fillRoundRect method
font
Font class
font metrics
font name
font style
FontMetrics class
GeneralPath class
getAscent method
getBlue method
getDescent method
getFamily method

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getFont method
getFontList method
getFontMetrics method
getGreen method
getHeight method
getLeading method
getName method
getRed method
getSize method
getStyle method
GradientPaint class
Graphics class
graphics context
graphics object
Graphics2D class
isBold method
isItalic method
isPlain method
Java2D API
leading
Line2D.Double class
lineTo method
Monospaced font
moveTo method
negative degrees
Paint interface
paint method
pixel
point
polygon
Polygon class
positive degrees
Rectangle2D.Double class
repaint method
RGB value
rotate method
RoundRectangle2D.Double class
SansSerif font
Serif font
setColor method
setFont method
setPaint method
setStroke method
Shape interface
Stroke interface
SystemColor class
TexturePaint class
translate method
update method
vertical component
x-axis
x-coordinate
y-axis
y-coordinate

SELF-REVIEW EXERCISES

11.1 Fill in the blanks in each of the following statements:

a) In Java2D, method _____ of class _____ sets the characteristics of a line used to draw a shape.
b) Class _____ helps define the fill for a shape such that the fill gradually changes from one color to another.
c) The _____ method of class **Graphics** draws a line between two points.
d) RGB is short for _____, _____ and _____.
e) Font sizes are measured in units called _____.
f) Class _____ helps define the fill for a shape using a pattern drawn in a **BufferedImage**.

11.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) The first two arguments of **Graphics** method drawOval specify the center coordinate of the oval.
b) In the Java coordinate system, *x* values increase from left to right.
c) Method **fillPolygon** draws a solid polygon in the current color.
d) Method **drawArc** allows negative angles.
e) Method **getSize** returns the size of the current font in centimeters.
f) Pixel coordinate *(0, 0)* is located at the exact center of the monitor.

11.3 Find the error(s) in each of the following and explain how to correct the error(s). Assume that **g** is a **Graphics** object.

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a) `g.setFont( "SansSerif" );`
b) `g.erase( x, y, w, h );  // clear rectangle at (x, y)`
c) `Font f = new Font( "Serif", Font.BOLDITALIC, 12 );`
d) `g.setColor( Color.Yellow );  // change color to yellow`

ANSWERS TO SELF-REVIEW EXERCISES

11.1 a) **`setStroke`**, **`Graphics2D`**. b) **`GradientPaint`**. c) **`drawLine`**. d) red, green, blue. e) points. f) **`TexturePaint`**.

11.2 a) False. The first two arguments specify the upper-left corner of the bounding rectangle.
b) True.
c) True.
d) True.
e) False. Font sizes are measured in points.
f) False. The coordinate *(0,0)* corresponds to the upper-left corner of a GUI component on which drawing occurs.

11.3 a) The **`setFont`** method takes a **`Font`** object as an argument—not a **`String`**.
b) The **`Graphics`** class does not have an **`erase`** method. The **`clearRect`** method should be used.
c) **`Font.BOLDITALIC`** is not a valid font style. To get a bold italic font, use **`Font.BOLD + Font.ITALIC`**.
d) **`Yellow`** should begin with a lowercase letter: **`g.setColor( Color.yellow );`**.

EXERCISES

11.4 Fill in the blanks in each of the following statements:
a) Class _____ of the Java2D API is used to define ovals.
b) Methods **`draw`** and **`fill`** of class **`Graphics2D`** require an object of type _____ as their argument.
c) The three constants that specify font style are _____, _____ and _____.
d) **`Graphics2D`** method _____ sets the painting color for Java2D shapes.

11.5 State whether each of the following is *true* or *false*. If *false*, explain why.
a) The **`drawPolygon`** method automatically connects the endpoints of the polygon.
b) The **`drawLine`** method draws a line between two points.
c) The **`fillArc`** method uses degrees to specify the angle.
d) In the Java coordinate system, *y* values increase from top to bottom.
e) The **`Graphics`** class inherits directly from class **`Object`**.
f) The **`Graphics`** class is an **`abstract`** class.
g) The **`Font`** class inherits directly from class **`Graphics`**.

11.6 Write a program that draws a series of eight concentric circles. The circles should be separated by 10 pixels. Use the **`drawOval`** method of class **`Graphics`**.

11.7 Write a program that draws a series of eight concentric circles. The circles should be separated by 10 pixels. Use the **`drawArc`** method.

11.8 Modify your solution to Exercise 11.6 to draw the ovals by using instances of class **`Ellipse2D.Double`** and method **`draw`** of class **`Graphics2D`**.

11.9 Write a program that draws lines of random lengths in random colors.

11.10 Modify your solution to Exercise 11.9 to draw random lines, in random colors and random line thicknesses. Use class **`Line2D.Double`** and method **`draw`** of class **`Graphics2D`** to draw the lines.

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11.11 Write a program that displays randomly generated triangles in different colors. Each triangle should be filled with a different color. Use class **GeneralPath** and method **fill** of class **Graphics2D** to draw the triangles.

11.12 Write a program that randomly draws characters in different font sizes and colors.

11.13 Write a program that draws an 8-by-8 grid. Use the **drawLine** method.

11.14 Modify your solution to Exercise 11.13 to draw the grid using instances of class **Line2D.Double** and method **draw** of class **Graphics2D**.

11.15 Write a program that draws a 10-by-10 grid. Use the **drawRect** method.

11.16 Modify your solution to Exercise 11.15 to draw the grid by using instances of class **Rectangle2D.Double** and method **draw** of class **Graphics2D**.

11.17 Write a program that draws a tetrahedron (a pyramid). Use class **GeneralPath** and method **draw** of class **Graphics2D**.

11.18 Write a program that draws a cube. Use class **GeneralPath** and method **draw** of class **Graphics2D**.

11.19 In Exercise 3.9, you wrote an applet that input the radius of a circle from the user and displayed the circle's diameter, circumference and area. Modify your solution to Exercise 3.9 to read a set of coordinates in addition to the radius. Then draw the circle and display the circle's diameter, circumference and area, using an **Ellipse2D.Double** object to represent the circle and method **draw** of class **Graphics2D** to display the circle.

11.20 Write an application that simulates a screen saver. The application should randomly draw lines using method **drawLine** of class **Graphics**. After drawing 100 lines, the application should clear itself and start drawing lines again. To allow the program to draw continuously, place a call to **repaint** as the last line in method **paint**. Do you notice any problems with this on your system?

11.21 Here is a peek ahead. Package **javax.swing** contains a class called ***Timer*** that is capable of calling method **actionPerformed** of interface **ActionListener** at a fixed time interval (specified in milliseconds). Modify your solution to Exercise 11.20 to remove the call to **repaint** from method **paint**. Define your class so it implements **ActionListener**. (The **actionPerformed** method should simply call **repaint**.) Define an instance variable of type **Timer** called **timer** in your class. In the constructor for your class, write the following statements:

```
timer = new Timer( 1000, this );
timer.start();
```

This creates an instance of class **Timer** that will call **this** object's **actionPerformed** method every **1000** milliseconds (i.e., every second).

11.22 Modify your solution to Exercise 11.21 to enable the user to enter the number of random lines that should be drawn before the application clears itself and starts drawing lines again. Use a **JTextField** to obtain the value. The user should be able to type a new number into the **JTextField** at any time during the program's execution. Use an inner class definition to perform event handling for the **JTextField**.

11.23 Modify your solution to Exercise 11.21 such that it uses random number generation to choose different shapes to display (use methods of class **Graphics**).]

11.24 Modify your solution to Exercise 11.23 to use classes and drawing capabilities of the Java2D API. For shapes such as rectangles and ellipses, draw them with randomly generated gradients (use class **GradientPaint** to generate the gradient).

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11.25 Write a graphical version of your solution to Exercise 6.37—the *Towers of Hanoi*. After studying Chapter 18, you will be able to implement a version of this exercise using Java's image, animation and audio capabilities.

11.26 Modify the die-rolling program of Fig. 7.8 so that it updates the counts for each side of the die after each roll. Convert the application into a windowed application (i.e., a subclass of **`JFrame`**) and use **`Graphics`** method **`drawString`** to output the totals.

11.27 Modify your solution to Exercise 7.21—*Turtle Graphics*—to add a graphical user interface using **`JTextField`**s and **`JButton`**s. Also, draw lines rather than drawing asterisks (**`*`**). When the turtle graphics program specifies a move, translate the number of positions into a number of pixels on the screen by multiplying the number of positions by 10 (or any value you choose). Implement the drawing with Java2D API features.

11.28 Produce a graphical version of the Knight's Tour problem (Exercises 7.22, 7.23 and 7.26). As each move is made, the appropriate cell of the chessboard should be updated with the proper move number. If the result of the program is a *full tour* or a *closed tour*, the program should display an appropriate message. If you would like, use class **`Timer`** (see Exercise 11.24) to help animate the Knight's Tour. Every second, the next move should be made.

11.29 Produce a graphical version of the *Tortoise and the Hare* simulation (Exercise 7.41). Simulate the mountain by drawing an arc that extends from the bottom-left of the window to the top-right of the window. The tortoise and the hare should race up the mountain. Implement the graphical output so the tortoise and the hare are actually printed on the arc every move. [Note: Extend the length of the race from 70 to 300 to allow yourself a larger graphics area.]

11.30 Produce a graphical version of the *Maze Traversal* problem (Exercises 7.38-7.40). Use the mazes you produced as guides for creating the graphical versions. While the maze is being solved, a small circle should be displayed in the maze indicating the current position. If you would like, use class **`Timer`** (see Exercise 11.24) to help animate the traversal of the maze. Every second, the next move should be made.

11.31 Produce a graphical version of the *Bucket Sort* (Exercise 7.28) that shows each value being placed into the appropriate bucket and eventually being copied back to the original array.

11.32 Write a program that uses method **`drawPolyline`** to draw a spiral.

11.33 Write a program that inputs four numbers and graphs the numbers as a pie chart. Use class **`Arc2D.Double`** and method **`fill`** of class **`Graphics2D`** to perform the drawing. Draw each piece of the pie in a separate color.

11.34 Write an applet that inputs four numbers and graphs the numbers as a bar graph. Use class **`Rectangle2D.Double`** and method **`fill`** of class **`Graphics2D`** to perform the drawing. Draw each bar in a different color.

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12

Graphical User Interface Components: Part 1

Objectives

- To understand the design principles of graphical user interfaces (GUI).
- To be able to build graphical user interfaces.
- To understand the packages containing GUI components and event-handling classes and interfaces.
- To be able to create and manipulate buttons, labels, lists, text fields and panels.
- To understand mouse events and keyboard events.
- To understand and be able to use layout managers.

… the wisest prophets make sure of the event first.
Horace Walpole

Do you think I can listen all day to such stuff?
Lewis Carroll

Speak the affirmative; emphasize your choice by utter ignoring of all that you reject.
Ralph Waldo Emerson

You pays your money and you takes your choice.
Punch

Guess if you can, choose if you dare.
Pierre Corneille

All hope abandon, ye who enter here!
Dante Alighieri

Exit, pursued by a bear.
William Shakespeare

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Outline

12.1 Introduction
12.2 Swing Overview
12.3 `JLabel`
12.4 Event-Handling Model
12.5 `JTextField` and `JPasswordField`
12.5.1 How Event Handling Works
12.6 `JButton`
12.7 `JCheckBox` and `JRadioButton`
12.8 `JComboBox`
12.10 Multiple-Selection Lists
12.11 Mouse Event Handling
12.12 Adapter Classes
12.13 Keyboard Event Handling
12.14 Layout Managers
12.14.1 `FlowLayout`
12.14.2 `BorderLayout`
12.14.3 `GridLayout`
12.15 Panels
12.16 (Optional Case Study) Thinking About Objects: Use Cases

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

12.1 Introduction

A *graphical user interface* (*GUI*) presents a pictorial interface to a program. A GUI (pronounced "GOO-EE") gives a program a distinctive "look" and "feel." Providing different programs with a consistent set of intuitive user interface components provides users with a basic level of familiarity with each program before they ever use it. In turn, this reduces the time users require to learn a program and increases their ability to use the program in a productive manner.

Look-and-Feel Observation 12.1

Consistent user interfaces enable a user to learn new applications faster.

As an example of a GUI, Fig. 12.1 contains a Netscape Navigator window with some of its GUI components labeled. In the window, there is a *menu bar* containing *menus* (**File**, **Edit**, **View** etc.). Below the menu bar there is a set of *buttons* that each have a defined task in Netscape Navigator. To the right of the buttons there is a *text field* in which the user can type the name of the World Wide Web site to visit. The menus, buttons and text fields are part of Netscape Navigator's GUI. They enable you to interact with the Navigator program.

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In this chapter and the next, we demonstrate many GUI components that enable users to interact with your programs.

GUIs are built from *GUI components* (sometimes called *controls* or *widgets*—shorthand notation for *window gadgets*). A GUI component is an object with which the user interacts via the mouse, the keyboard or another form of input, such as voice recognition. Several common GUI components are listed in Figure 12.2. In the sections that follow, we discuss each of these GUI components in detail. In the next chapter, we discuss more advanced GUI components.

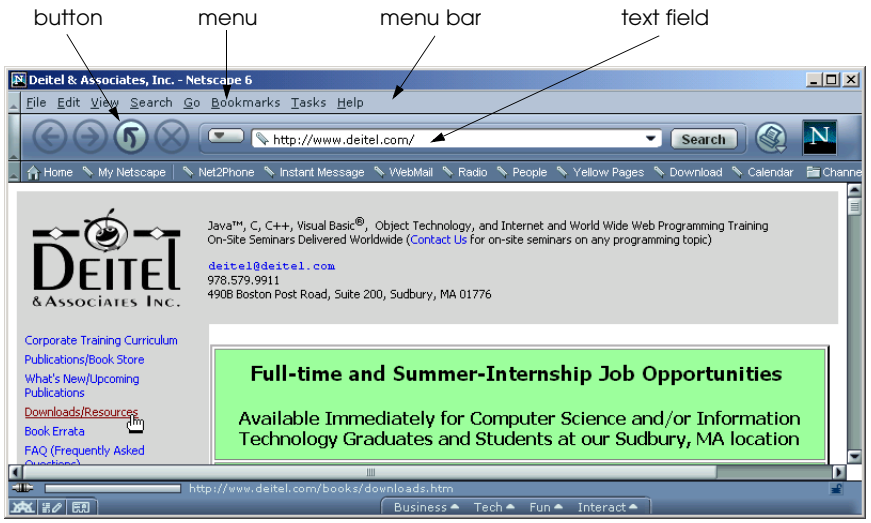

Fig. 12.1 A sample Netscape Navigator window with GUI components.

Component	Description
`JLabel`	An area where uneditable text or icons can be displayed.
`JTextField`	An area in which the user inputs data from the keyboard. The area can also display information.
`JButton`	An area that triggers an event when clicked.
`JCheckBox`	A GUI component that is either selected or not selected.
`JComboBox`	A drop-down list of items from which the user can make a selection by clicking an item in the list or possibly by typing into the box.
`JList`	An area where a list of items is displayed from which the user can make a selection by clicking once on any element in the list. Double-clicking an element in the list generates an action event. Multiple elements can be selected.
`JPanel`	A container in which components can be placed.

Fig. 12.2 Some basic GUI components.

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12.2 Swing Overview

The classes that create the GUI components of Fig. 12.2 are part of the *Swing GUI components* from package **`javax.swing`**. These GUI components became standard in Java with the release of the Java 2 platform version 1.2. Most *Swing components* (as they are commonly called) are written, manipulated and displayed completely in Java (so-called *pure Java* components).

The original GUI components from the *Abstract Windowing Toolkit* package **`java.awt`** (also called the *AWT*) are tied directly to the local platform's graphical user interface capabilities. When a Java program with an AWT GUI executes on different Java platforms, the program's GUI components display differently on each platform. Consider a program that displays an object of type **`Button`** (package **`java.awt`**). On a computer running the Microsoft Windows operating system, the **`Button`** will have the same look and feel as the buttons in other Windows applications. Similarly, on a computer running the Apple Macintosh operating system, the **`Button`** will have the same look and feel as the buttons in other Macintosh applications. In addition to the differences in appearance, sometimes the manner in which a user interacts with a particular AWT component differs between platforms.

Together, the appearance and how the user interacts with the program are known as that program's *look and feel*. The Swing components allow the programmer to specify a uniform look and feel across all platforms. In addition, Swing enables programs to provide a custom look and feel for each platform or even to change the look and feel while the program is running. For example, a program could enable users to choose their preferred look and feel.

Look-and-Feel Observation 12.2

Swing components are written in Java, so they provide a greater level of portability and flexibility than the original Java GUI components from package **`java.awt`**.

Swing components are often referred to as *lightweight components*—they are written completely in Java so they are not "weighed down" by the complex GUI capabilities of the platform on which they are used. AWT components (many of which parallel the Swing components) that are tied to the local platform are correspondingly called *heavyweight components*—they rely on the local platform's *windowing system* to determine their functionality and their look and feel. Each heavyweight component has a *peer* (from package **`java.awt.peer`**) that is responsible for the interactions between the component and the local platform that display and manipulate the component. Several Swing components are still heavyweight components. In particular, subclasses of **`java.awt.Window`** (such as **`JFrame`** used in several previous chapters) that display windows on the screen and subclasses of **`java.applet.Applet`** (such as **`JApplet`**) still require direct interaction with the local windowing system. As such, heavyweight Swing GUI components are less flexible than many of the lightweight components we will demonstrate.

Portability Tip 12.1

The look of a GUI defined with heavyweight GUI components from package **`java.awt`** *may vary across platforms. Heavyweight components "tie" into the "local" platform GUI, which varies from platform to platform.*

Figure 12.3 shows an inheritance hierarchy of the classes that define attributes and behaviors that are common to most Swing components. Each class is displayed with its

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fully qualified package name and class name. Much of each GUI component's functionality is derived from these classes. A class that inherits from the **`Component`** class *is a* **`Component`**. For example, class **`Container`** inherits from class **`Component`**, and class **`Component`** inherits from **`Object`**. Thus, a **`Container`** *is a* **`Component`** and *is an* **`Object`**, and a **`Component`** *is an* **`Object`**. A class that inherits from class **`Container`** *is a* **`Container`**. Thus, a **`JComponent`** *is a* **`Container`**.

Software Engineering Observation 12.1

To use GUI components effectively, the **`javax.swing`** *and* **`java.awt`** *inheritance hierarchies must be understood—especially class* **`Component`**, *class* **`Container`** *and class* **`JComponent`**, *which define features common to most Swing components.*

Class **`Component`** defines the common attributes and behaviors of all subclasses of **`Component`**. With few exceptions, most GUI components extend class **`Component`** directly or indirectly. One method that originates in class **`Component`** that has been used frequently to this point is **`paint`**. Other methods discussed previously that originated in Component are **`repaint`** and **`update`**. It is important to understand the methods of class **`Component`** because much of the functionality inherited by every subclass of **`Component`** is defined by the **`Component`** class originally. Operations common to most GUI components (both Swing and AWT) are found in class **`Component`**.

Good Programming Practice 12.1

Study the methods of class **`Component`** *in the Java 2 SDK on-line documentation to learn the capabilities common to most GUI components.*

A **`Container`** is a collection of related components. In applications with **`JFrame`**s and in applets, we attach components to the content pane, which is an object of class **`Container`**. Class **`Container`** defines the common attributes and behaviors for all subclasses of **`Container`**. One method that originates in class **`Container`** is **`add`** for adding components to a **`Container`**. Another method that originates in class **`Container`** is **`setLayout`**, which enables a program to specify the layout manager that helps a **`Container`** position and size its components.

Good Programming Practice 12.2

Study the methods of class **`Container`** *in the Java 2 SDK on-line documentation to learn the capabilities common to every container for GUI components.*

Class **`JComponent`** is the superclass to most Swing components. This class defines the common attributes and behaviors of all subclasses of **`JComponent`**.

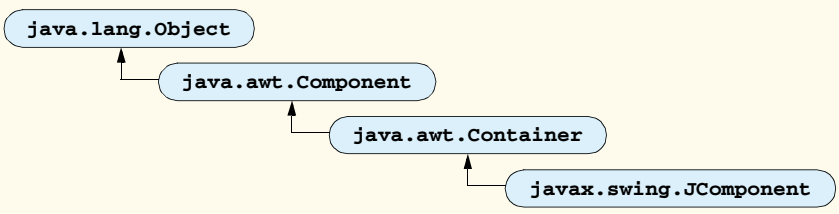

Fig. 12.3 Common superclasses of many of the Swing components.

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Good Programming Practice 12.3

Study the methods of class **`JComponent`** *in the Java 2 SDK on-line documentation to learn the capabilities common to every container for GUI components.*

Swing components that subclass **`JComponent`** have many features, including:

1. A *pluggable look and feel* that can be used to customize the look and feel when the program executes on different platforms.
2. Shortcut keys (called *mnemonics*) for direct access to GUI components through the keyboard.
3. Common event-handling capabilities for cases where several GUI components initiate the same actions in a program.
4. Brief descriptions of a GUI component's purpose (called *tool tips*) that are displayed when the mouse cursor is positioned over the component for a short time.
5. Support for assistive technologies such as braille screen readers for blind people.
6. Support for user interface *localization*—customizing the user interface for display in different languages and cultural conventions.

These are just some of the many features of the Swing components. We discuss several of these features here and in Chapter 13.

12.3 `JLabel`

Labels provide text instructions or information on a GUI. Labels are defined with class **`JLabel`**—a subclass of **`JComponent`**. A label displays a single line of *read-only text*, an image or both text and an image. Programs rarely change a label's contents after creating it. The application of Figure 12.4 demonstrates several **`JLabel`** features.

```
1  // Fig. 12.4: LabelTest.java
2  // Demonstrating the JLabel class.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class LabelTest extends JFrame {
12    private JLabel label1, label2, label3;
13
14    // set up GUI
15    public LabelTest()
16    {
17       super( "Testing JLabel" );
18
```

Fig. 12.4 Demonstrating class **`JLabel`** (part 1 of 2).

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```
19          // get content pane and set its layout
20          Container container = getContentPane();
21          container.setLayout( new FlowLayout() );
22
23          // JLabel constructor with a string argument
24          label1 = new JLabel( "Label with text" );
25          label1.setToolTipText( "This is label1" );
26          container.add( label1 );
27
28          // JLabel constructor with string, Icon and
29          // alignment arguments
30          Icon bug = new ImageIcon( "bug1.gif" );
31          label2 = new JLabel( "Label with text and icon",
32             bug, SwingConstants.LEFT );
33          label2.setToolTipText( "This is label2" );
34          container.add( label2 );
35
36          // JLabel constructor no arguments
37          label3 = new JLabel();
38          label3.setText( "Label with icon and text at bottom" );
39          label3.setIcon( bug );
40          label3.setHorizontalTextPosition( SwingConstants.CENTER );
41          label3.setVerticalTextPosition( SwingConstants.BOTTOM );
42          label3.setToolTipText( "This is label3" );
43          container.add( label3 );
44
45          setSize( 275, 170 );
46          setVisible( true );
47       }
48
49       // execute application
50       public static void main( String args[] )
51       {
52          LabelTest application = new LabelTest();
53
54          application.setDefaultCloseOperation(
55             JFrame.EXIT_ON_CLOSE );
56       }
57
58    }  // end class LabelTest
```

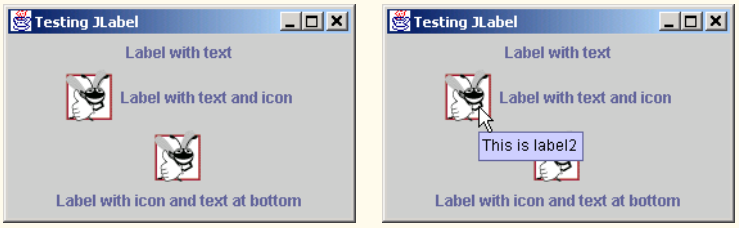

Fig. 12.4 Demonstrating class **JLabel** (part 2 of 2).

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Good Programming Practice 12.4

Study the methods of class ***javax.swing.JLabel*** *in the Java 2 SDK on-line documentation to learn the complete capabilities of the class before using it.*

The program declares three **JLabel**s at line 12. The **JLabel** objects are instantiated in the **LabelTest** constructor (line 15–47). Line 24 creates a **JLabel** object with the text **"Label with text"**. The label displays this text when the label appears on the screen (i.e., when the window is displayed in this program).

Line 25 uses method ***setToolTipText*** (inherited into class **JLabel** from class **JComponent**) to specify the tool tip (see the second screen capture in Fig. 12.4) that is displayed automatically when the user positions the mouse cursor over the label in the GUI. When you execute this program, try positioning the mouse over each label to see its tool tip. Line 26 adds **label1** to the content pane.

Look-and-Feel Observation 12.3

Use tool tips (set with ***JComponent*** *method* ***setToolTipText****) to add descriptive text to your GUI components. This text helps the user determine the GUI component's purpose in the user interface.*

Several Swing components can display images by specifying an ***Icon*** as an argument to their constructor or by using a method that is normally called ***setIcon***. An **Icon** is an object of any class that implements interface ***Icon*** (package **javax.swing**). One such class is ***ImageIcon*** (package **javax.swing**), which supports several image formats, including *Graphics Interchange Format (GIF)*, *Portable Network Graphics (PNG)* and *Joint Photographic Experts Group (JPEG)*. File names for each of these types typically end with **.gif**, **.png** or **.jpg** (or **.jpeg**), respectively. We discuss images in more detail in Chapter 18, Multimedia. Line 30 defines an **ImageIcon** object. The file **bug1.gif** contains the image to load and store in the **ImageIcon** object. This file is assumed to be in the same directory as the program (we will discuss locating the file elsewhere in Chapter 18). The **ImageIcon** object is assigned to **Icon** reference **bug**. Remember, class **ImageIcon** implements interface **Icon**, therefore an **ImageIcon** *is an* **Icon**.

Class **JLabel** supports the display of **Icon**s. Lines 31–32 use another **JLabel** constructor to create a label that displays the text **"Label with text and icon"** and the **Icon** to which **bug** refers and is *left justified* or *left aligned* (i.e., the icon and text are at the left side of the label's area on the screen). Interface ***SwingConstants*** (package **javax.swing**) defines a set of common integer constants (such as **SwingConstants.LEFT**) that are used with many Swing components. By default, the text appears to the right of the image when a label contains both text and an image. The horizontal and vertical alignments of a label can be set with methods ***setHorizontalAlignment*** and ***setVerticalAlignment***, respectively. Line 33 specifies the tool tip text for **label2**. Line 34 adds **label2** to the content pane.

Common Programming Error 12.1

If you do not explicitly add a GUI component to a container, the GUI component will not be displayed when the container appears on the screen.

Common Programming Error 12.2

Adding to a container a component that has not been instantiated throws a ***NullPointerException****.*

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Class **JLabel** provides many methods to configure a label after it has been instantiated. Line 37 creates a **JLabel** and invokes the no-argument (default constructor). Such a label has no text or **Icon**. Line 38 uses **JLabel** method ***setText*** to set the text displayed on the label. A corresponding method ***getText*** retrieves the current text displayed on a label. Line 39 uses **JLabel** method ***setIcon*** to set the **Icon** displayed on the label. A corresponding method ***getIcon*** retrieves the current **Icon** displayed on a label. Lines 40–41 use **JLabel** methods ***setHorizontalTextPosition*** and ***setVerticalTextPosition*** to specify the text position in the label. In this case, the text will be centered horizontally and will appear at the bottom of the label. Thus, the **Icon** will appear above the text. Line 42 sets the tool tip text for the **label3**. Line 43 adds **label3** to the content pane.

12.4 Event-Handling Model

In the preceding section, we did not discuss event handling because there are no specific events for **JLabel** objects. GUIs are *event driven* (i.e., they generate *events* when the user of the program interacts with the GUI). Some common interactions are moving the mouse, clicking the mouse, clicking a button, typing in a text field, selecting an item from a menu, closing a window, etc. When a user interaction occurs, an event is sent to the program. GUI event information is stored in an object of a class that extends **AWTEvent**. Figure 12.5 illustrates a hierarchy containing many of the event classes we use from package **java.awt.event**. Many of these event classes are discussed throughout this chapter and Chapter 13. The event types from package ***java.awt.event*** are used with both AWT and Swing components. Additional event types have also been added that are specific to several types of Swing components. New Swing-component event types are defined in package ***javax.swing.event***.

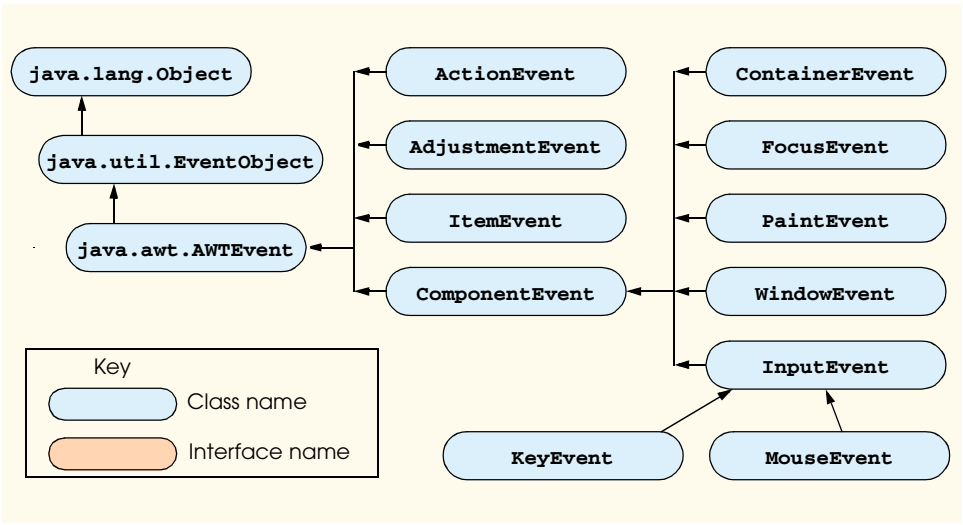

Fig. 12.5 Some event classes of package **java.awt.event**.

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There are three parts to the event-handling mechanism—the *event source*, the *event object* and the *event listener*. The event source is the particular GUI component with which the user interacts. The event object encapsulates information about the event that occurred. This information includes a reference to the event source and any event-specific information that may be required by the event listener to handle the event. The event listener is an object that is notified by the event source when an event occurs. The event listener receives an event object when it is notified of the event, then uses the object to respond to the event. The event source is required to provide methods that enable listeners to be registered and unregistered. The event source also is required to maintain a list of its registered listeners and be able to notify its listeners when an event occurs.

The programmer must perform two key tasks to process a graphical user interface event in a program—register an *event listener* for the GUI component that is expected to generate the event, and implement an *event handling method* (or set of event-handling methods). Commonly, event-handling methods are called *event handlers*. An event listener for a GUI event is an object of a class that implements one or more of the event-listener interfaces from package **`java.awt.event`** and package **`javax.swing.event`**. Many of the event-listener types are common to both Swing and AWT components. Such types are defined in package **`java.awt.event`**, and many of these are shown in Fig. 12.6. Additional event-listener types that are specific to Swing components are defined in package **`javax.swing.event`**.

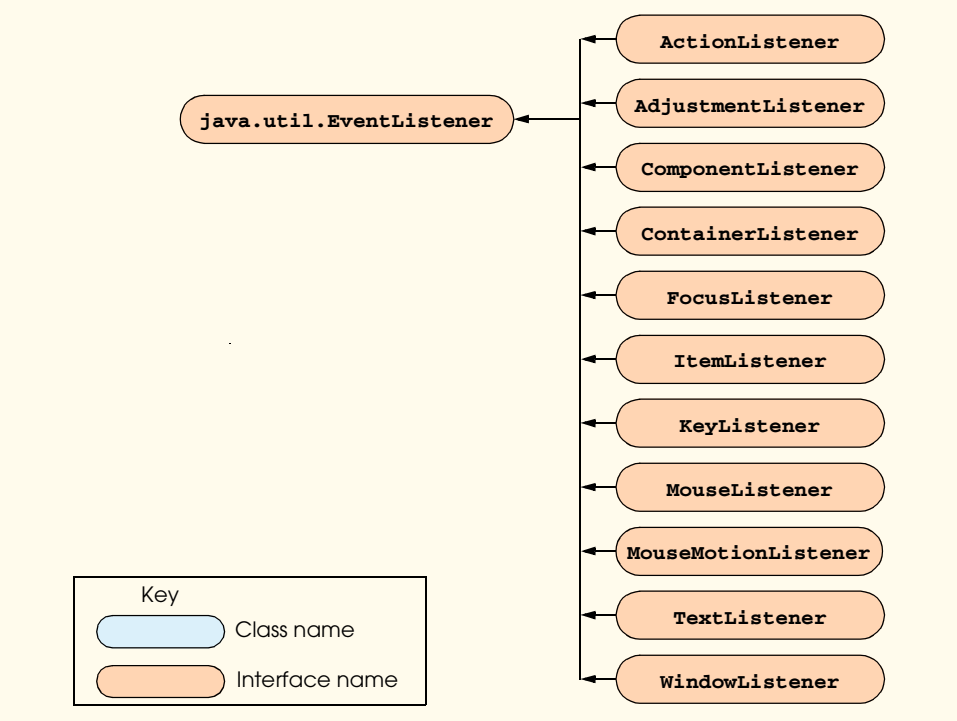

Fig. 12.6 Event-listener interfaces of package **`java.awt.event`**.

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An event listener object "listens" for specific types of events generated by event sources (normally GUI components) in a program. An event handler is a method that is called in response to a particular type of event. Each event-listener interface specifies one or more event-handling methods that *must* be defined in the class that implements the event-listener interface. Remember that interfaces define **`abstract`** methods. Any class that implements an interface must define all the methods of that interface; otherwise, the class is an **`abstract`** class and cannot be used to create objects. The use of event listeners in event handling is known as the *delegation event model*—the processing of an event is delegated to a particular object (the listener) in the program.

When an event occurs, the GUI component with which the user interacted notifies its registered listeners by calling each listener's appropriate event handling method. For example, when the user presses the *Enter* key in a **`JTextField`**, the registered listener's **`actionPerformed`** method is called. How did the event handler get registered? How does the GUI component know to call **`actionPerformed`** as opposed to some other event handling method? We answer these questions and diagram the interaction as part of the next example.

12.5 `JTextField` and `JPasswordField`

`JTextField``s` and ***`JPasswordField`***`s` (package **`javax.swing`**) are single-line areas in which text can be entered by the user from the keyboard or text can simply be displayed. A **`JPasswordField`** shows that a character was typed as the user enters characters, but hides the characters, assuming that they represent a password that should remain known only to the user. When the user types data into a **`JTextField`** or **`JPasswordField`** and presses the *Enter* key, an action event occurs. If the program registers an event listener, the listener processes the event and can use the data in the **`JTextField`** or **`JPasswordField`** at the time of the event in the program. Class **`JTextField`** extends class ***`JTextComponent`*** (package **`javax.swing.text`**), which provides many features common to Swing's text-based components. Class **`JPasswordField`** extends **`JTextField`** and adds several methods that are specific to processing passwords.

Common Programming Error 12.3

Using a lowercase **`f`** *in the class names* ***`JTextField`*** *or* ***`JPasswordField`*** *is a syntax error.*

The application of Fig. 12.7 uses classes **`JTextField`** and **`JPasswordField`** to create and manipulate four fields. When the user presses *Enter* in the currently active field (the currently active component "has the *focus*"), a message dialog box containing the text in the field is displayed. When an event occurs in the **`JPasswordField`**, the password is revealed.

```
1  // Fig. 12.7: TextFieldTest.java
2  // Demonstrating the JTextField class.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
```

Fig. 12.7 Demonstrating **`JTextField`**s and **`JPasswordField`**s (part 1 of 4).

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```
 7
 8  // Java extension packages
 9  import javax.swing.*;
10
11  public class TextFieldTest extends JFrame {
12     private JTextField textField1, textField2, textField3;
13     private JPasswordField passwordField;
14
15     // set up GUI
16     public TextFieldTest()
17     {
18        super( "Testing JTextField and JPasswordField" );
19
20        Container container = getContentPane();
21        container.setLayout( new FlowLayout() );
22
23        // construct textfield with default sizing
24        textField1 = new JTextField( 10 );
25        container.add( textField1 );
26
27        // construct textfield with default text
28        textField2 = new JTextField( "Enter text here" );
29        container.add( textField2 );
30
31        // construct textfield with default text and
32        // 20 visible elements and no event handler
33        textField3 = new JTextField( "Uneditable text field", 20 );
34        textField3.setEditable( false );
35        container.add( textField3 );
36
37        // construct textfield with default text
38        passwordField = new JPasswordField( "Hidden text" );
39        container.add( passwordField );
40
41        // register event handlers
42        TextFieldHandler handler = new TextFieldHandler();
43        textField1.addActionListener( handler );
44        textField2.addActionListener( handler );
45        textField3.addActionListener( handler );
46        passwordField.addActionListener( handler );
47
48        setSize( 325, 100 );
49        setVisible( true );
50     }
51
52     // execute application
53     public static void main( String args[] )
54     {
55        TextFieldTest application = new TextFieldTest();
56
57        application.setDefaultCloseOperation(
58           JFrame.EXIT_ON_CLOSE );
59     }
```

Fig. 12.7 Demonstrating **`JTextField`**s and **`JPasswordField`**s (part 2 of 4).

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```
60
61     // private inner class for event handling
62     private class TextFieldHandler implements ActionListener {
63
64        // process text field events
65        public void actionPerformed( ActionEvent event )
66        {
67           String string = "";
68
69           // user pressed Enter in JTextField textField1
70           if ( event.getSource() == textField1 )
71              string = "textField1: " + event.getActionCommand();
72
73           // user pressed Enter in JTextField textField2
74           else if ( event.getSource() == textField2 )
75              string = "textField2: " + event.getActionCommand();
76
77           // user pressed Enter in JTextField textField3
78           else if ( event.getSource() == textField3 )
79              string = "textField3: " + event.getActionCommand();
80
81           // user pressed Enter in JTextField passwordField
82           else if ( event.getSource() == passwordField ) {
83              JPasswordField pwd =
84                 ( JPasswordField ) event.getSource();
85              string = "passwordField: " +
86                  new String( passwordField.getPassword() );
87           }
88
89           JOptionPane.showMessageDialog( null, string );
90        }
91
92     }  // end private inner class TextFieldHandler
93
94  }  // end class TextFieldTest
```

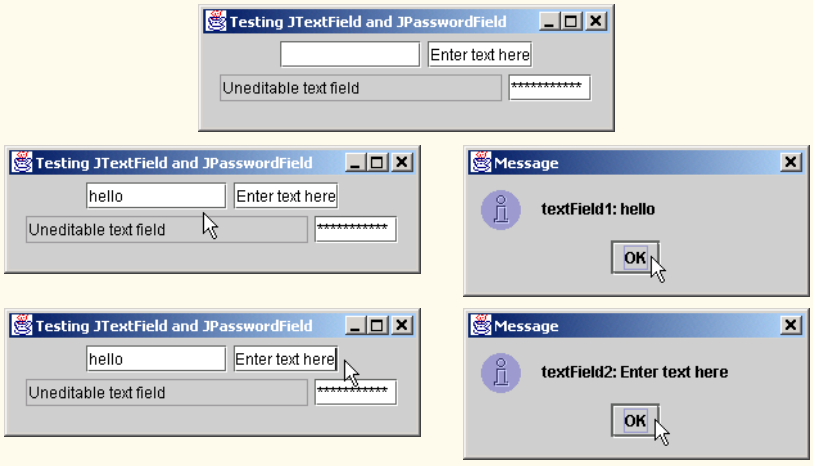

Fig. 12.7 Demonstrating **JTextField**s and **JPasswordField**s (part 3 of 4).

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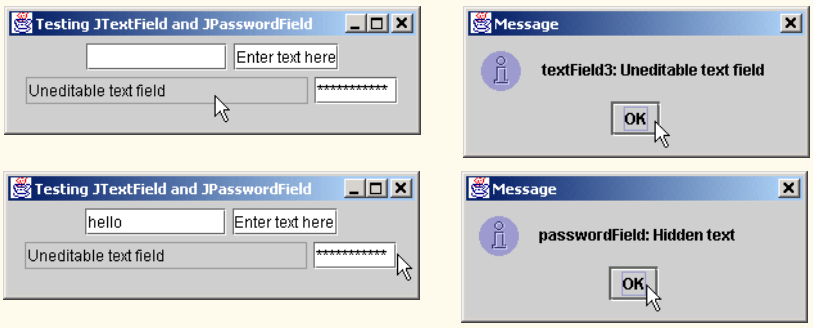

Fig. 12.7 Demonstrating **JTextField**s and **JPasswordField**s (part 4 of 4).

Lines 12–13 declare three references for **JTextField**s (**textField1**, **textField2** and **textField3**) and a **JPasswordField** (**passwordField**). Each of these is instantiated in the constructor (line 16–50). Line 24 defines **JTextField textField1** with **10** columns of text. The width of the text field will be the width in pixels of the average character in the text field's current font multiplied by 10. Line 25 adds **textField1** to the content pane.

Line 28 defines **textField2** with the initial text **"Enter text here"** to display in the text field. The width of the text field is determined by the text. Line 29 adds **textField2** to the content pane.

Line 33 defines **textField3** and call the **JTextField** constructor with two arguments—the default text **"Uneditable text field"** to display in the text field and the number of columns (**20**). The width of the text field is determined by the number of columns specified. Line 34 uses method ***setEditable*** (inherited into **JTextField** from class **JTextComponent**) to indicate that the user cannot modify the text in the text field. Line 35 adds **textField3** to the content pane.

Line 38 defines **JPasswordField passwordField** with the text **"Hidden text"** to display in the text field. The width of the text field is determined by the text. Notice that the text is displayed as a string of asterisks when the program executes. Line 39 adds **passwordField** to the content pane.

For the event-handling in this example, we defined inner class **TextFieldHandler** (lines 62–92), which implements interface **ActionListener** (class **TextFieldHandler** is discussed shortly). Thus, every instance of class **TextFieldHandler** *is an* **ActionListener**. Line 42 defines an instance of class **TextFieldHandler** and assigns it to reference **handler**. This one instance will be used as the event-listener object for the **JTextField**s and the **JPasswordField** in this example.

Lines 43–46 are the event registration statements that specify the event listener object for each of the three **JTextField**s and for the **JPasswordField**. After these statements execute, the object to which **handler** refers is *listening for events* (i.e., it will be notified when an event occurs) on these four objects. The program calls **JTextField** method **addActionListener** to register the event for each component. Method **addActionListener** receives as its argument an **ActionListener** object. Thus, any object of a class that implements interface **ActionListener** (i.e., any object that *is an* **Action-**

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Listener) can be supplied as an argument to this method. The object to which **handler** refers *is an* **ActionListener** because its class implements interface **ActionListener**. Now, when the user presses *Enter* in any of these four fields, method **actionPerformed** (line 65–90) in class **TextFieldHandler** is called to handle the event.

Software Engineering Observation 12.2

The event listener for an event must implement the appropriate event-listener interface.

Method **actionPerformed** uses its **ActionEvent** argument's method **getSource** to determine the GUI component with which the user interacted and creates a **String** to display in a message dialog box. **ActionEvent** method **getActionCommand** returns the text in the **JTextField** that generated the event. If the user interacted with the **JPasswordField**, lines 83–84 cast the **Component** reference returned by **event.getSource()** to a **JPasswordField** reference so that lines 85–86 can use **JPasswordField** method ***getPassword*** to obtain the password and create the **String** to display. Method **getPassword** returns the password as an array of type **char** that is used as an argument to a **String** constructor to create a **String**. Line 89 displays a message box indicating the GUI component reference name and the text the user typed in the field.

Note that even an uneditable **JTextField** can generate an event. Simply click the text field, then press *Enter*. Also note that the actual text of the password is displayed when you press *Enter* in the **JPasswordField** (of course, you would normally not do this!).

Common Programming Error 12.4

Forgetting to register an event handler object for a particular GUI component's event type results in no events being handled for that component for that event type.

Using a separate class to define an event listener is a common programming practice for separating the GUI interface from the implementation of its event handler. For the remainder of this chapter and Chapter 13, many programs use separate event-listener classes to process GUI events.

12.5.1 How Event Handling Works

Let us illustrate how the event-handling mechanism works using **textField1** from the preceding example. We have two remaining open questions from Section 12.4:

1. How did the event handler get registered?
2. How does the GUI component know to call **actionPerformed** as opposed to some other event handling method?

The first question is answered by the event registration performed in lines 43–46 of the program. Figure 12.8 diagrams **JTextField** reference **textField1**, the **JTextField** object to which it refers and the listener object that is registered to handle the **JTextField**'s event.

Every **JComponent** has an object of class ***EventListenerList*** (package **javax.swing.event**) called ***listenerList*** as an instance variable. All registered listeners are stored in the **listenerList** (diagramed as an array in Figure 12.8). When the statement

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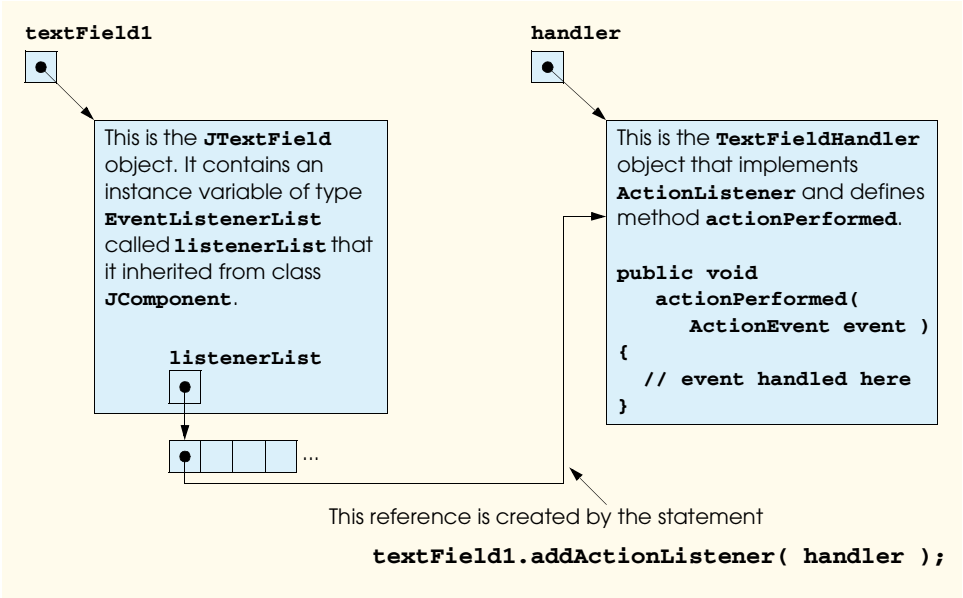

Fig. 12.8 Event registration for **JTextField textField1**.

```
textField1.addActionListener( handler );
```

executes in Fig. 12.7, a new entry is placed in the **listenerList** for **JTextField textField1**, indicating both the reference to the listener object and the type of listener (in this case **ActionListener**).

The type is important in answering the second question—how does the GUI component know to call **actionPerformed** rather than another event handling method? Every **JComponent** actually supports several different event types, including *mouse events*, *key events* and others. When an event occurs, the event is *dispatched* only to the event listeners of the appropriate type. The dispatching of an event is simply calling the event handling method for each registered listener for that event type.

Each event type has a corresponding event-listener interface. For example, **ActionEvent**s are handled by **ActionListener**s, ***MouseEvent**s* are handled by ***MouseListener**s* (and ***MouseMotionListener**s* as we will see) and ***KeyEvent**s* are handled by ***KeyListener**s*. When an event is generated by a user interaction with a component, the component is handed a unique *event ID* specifying the event type that occurred. The GUI component uses the event ID to decide the type of listener to which the event should be dispatched and the method to call. In the case of an **ActionEvent**, the event is dispatched to every registered **ActionListener**'s **actionPerformed** method (the only method in interface **ActionListener**). In the case of a **MouseEvent**, the event is dispatched to every registered **MouseListener** (or **MouseMotionListener**, depending on the event that occurs). The event ID of the **MouseEvent** determines which of the seven different mouse event handling methods are called. All of this decision logic is handled for you by the GUI components. We discuss other event types and event-listener interfaces as they are needed with each new component we cover.

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12.6 JButton

A *button* is a component the user clicks to trigger a specific action. A Java program can use several types of buttons, including *command buttons*, *check boxes*, *toggle buttons* and *radio buttons*. Figure 12.9 shows the inheritance hierarchy of the Swing buttons we cover in this chapter. As you can see in the diagram, all the button types are subclasses of **AbstractButton** (package **javax.swing**), which defines many of the features that are common to Swing buttons. In this section, we concentrate on buttons that are typically used to initiate a command. Other button types are covered in the next several sections.

A command button generates an **ActionEvent** when the user clicks the button with the mouse. Command buttons are created with class **JButton**, which inherits from class **AbstractButton**. The text on the face of a **JButton** is called a *button label*. A GUI can have many **JButton**s, but each button label typically should be unique.

Look-and-Feel Observation 12.4

Having more than one **JButton** *with the same label makes the* **JButton**s *ambiguous to the user. Be sure to provide a unique label for each button.*

The application of Fig. 12.10 creates two **JButton**s and demonstrates that **JButton**s (like **JLabel**s) support the display of **Icon**s. Event handling for the buttons is performed by a single instance of inner class **ButtonHandler** (defined at lines 53–62).

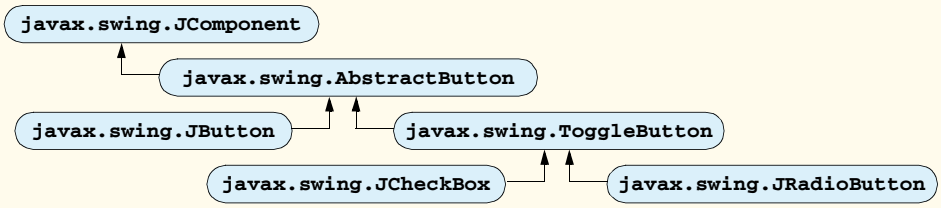

Fig. 12.9 The button hierarchy.

```
1  // Fig. 12.10: ButtonTest.java
2  // Creating JButtons.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class ButtonTest extends JFrame {
12    private JButton plainButton, fancyButton;
```

Fig. 12.10 Demonstrating command buttons and action events (part 1 of 3).

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```
13
14    // set up GUI
15    public ButtonTest()
16    {
17       super( "Testing Buttons" );
18
19       // get content pane and set its layout
20       Container container = getContentPane();
21       container.setLayout( new FlowLayout() );
22
23       // create buttons
24       plainButton = new JButton( "Plain Button" );
25       container.add( plainButton );
26
27       Icon bug1 = new ImageIcon( "bug1.gif" );
28       Icon bug2 = new ImageIcon( "bug2.gif" );
29       fancyButton = new JButton( "Fancy Button", bug1 );
30       fancyButton.setRolloverIcon( bug2 );
31       container.add( fancyButton );
32
33       // create an instance of inner class ButtonHandler
34       // to use for button event handling
35       ButtonHandler handler = new ButtonHandler();
36       fancyButton.addActionListener( handler );
37       plainButton.addActionListener( handler );
38
39       setSize( 275, 100 );
40       setVisible( true );
41    }
42
43    // execute application
44    public static void main( String args[] )
45    {
46       ButtonTest application = new ButtonTest();
47
48       application.setDefaultCloseOperation(
49          JFrame.EXIT_ON_CLOSE );
50    }
51
52    // inner class for button event handling
53    private class ButtonHandler implements ActionListener {
54
55       // handle button event
56       public void actionPerformed( ActionEvent event )
57       {
58          JOptionPane.showMessageDialog( null,
59             "You pressed: " + event.getActionCommand() );
60       }
61
62    }  // end private inner class ButtonHandler
63
64 }  // end class ButtonTest
```

Fig. 12.10 Demonstrating command buttons and action events (part 2 of 3).

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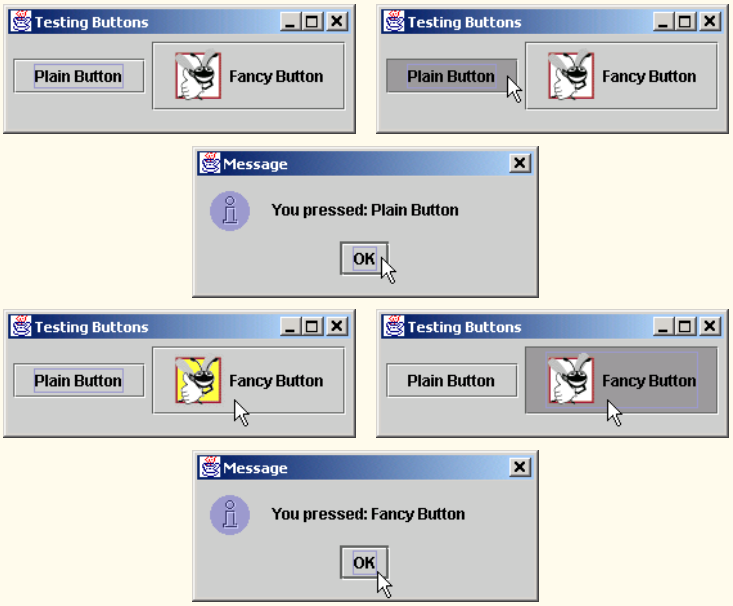

Fig. 12.10 Demonstrating command buttons and action events (part 3 of 3).

Line 12 declares two references to instances of class **`JButton`**—**`plainButton`** and **`fancyButton`**—that are instantiated in the constructor.

Line 24 creates **`plainButton`** with the button label **`"Plain Button"`**. Line 25 adds the button to the content pane.

A **`JButton`** can display **`Icon`**s. To provide the user with an extra level of visual interactivity with the GUI, a **`JButton`** can also have a *rollover* **`Icon`**—an **`Icon`** that is displayed when the mouse is positioned over the button. The icon on the button changes as the mouse moves in and out of the button's area on the screen. Lines 27–28 create two **`ImageIcon`** objects that represent the default **`Icon`** and rollover **`Icon`** for the **`JButton`** created at line 29. Both statements assume the image files are stored in the same directory as the program (this is commonly the case for applications that use images).

Line 29 creates **`fancyButton`** with default text **`"Fancy Button"`** and the **`Icon`** **`bug1`**. By default, the text is displayed to the right of the icon. Line 30 uses method ***`setRolloverIcon`*** (inherited from class **`AbstractButton`** into class **`JButton`**) to specify the image displayed on the button when the user positions the mouse over the button. Line 31 adds the button to the content pane.

Look-and-Feel Observation 12.5

*Using rollover icons for **`JButton`**s provides the user with visual feedback indicating that if they click the mouse, the button's action will occur.*

`JButton`s (like **`JTextField`**s) generate **`ActionEvent`**s. As mentioned previously, an **`ActionEvent`** can be processed by any **`ActionListener`** object. Lines 35–37 register an **`ActionListener`** object for each **`JButton`**. Inner class **`ButtonHandler`** (lines 53–62) defines **`actionPerformed`** to display a message dialog box con-

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taining the label for the button that was pressed by the user. **ActionEvent** method **getActionCommand** returns the label on the button that generated the event.

12.7 JCheckBox and JRadioButton

The Swing GUI components contain three types of *state buttons*—***JToggleButton***, ***JCheckBox*** and ***JRadioButton***—that have on/off or true/false values. **JToggleButton**s are frequently used with *toolbars* (sets of small buttons typically located on a bar across the top of a window) and are covered in Chapter 13. Classes **JCheckBox** and **JRadioButton** are subclasses of **JToggleButton**. A **JRadioButton** is different from a **JCheckBox** in that there are normally several **JRadioButton**s that are grouped together and only one of the **JRadioButton**s in the group can be selected (true) at any time. We first discuss class **JCheckBox**.

Look-and-Feel Observation 12.6

*Because class **AbstractButton** supports displaying text and images on a button, all subclasses of **AbstractButton** also support displaying text and images.*

The application of Fig. 12.11 uses two **JCheckBox** objects to change the font style of the text displayed in a **JTextField**. One **JCheckBox** applies a bold style when selected and the other applies an italic style when selected. If both are selected, the style of the font is bold and italic. When the program initially executes, neither **JCheckBox** is checked (**true**).

```
1  // Fig. 12.11: CheckBoxTest.java
2  // Creating Checkbox buttons.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class CheckBoxTest extends JFrame {
12    private JTextField field;
13    private JCheckBox bold, italic;
14
15    // set up GUI
16    public CheckBoxTest()
17    {
18       super( "JCheckBox Test" );
19
20       // get content pane and set its layout
21       Container container = getContentPane();
22       container.setLayout( new FlowLayout() );
23
24       // set up JTextField and set its font
25       field =
26          new JTextField( "Watch the font style change", 20 );
```

Fig. 12.11 Program that creates two **JCheckBox** buttons (part 1 of 3).

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```
27          field.setFont( new Font( "Serif", Font.PLAIN, 14 ) );
28          container.add( field );
29
30          // create checkbox objects
31          bold = new JCheckBox( "Bold" );
32          container.add( bold );
33
34          italic = new JCheckBox( "Italic" );
35          container.add( italic );
36
37          // register listeners for JCheckBoxes
38          CheckBoxHandler handler = new CheckBoxHandler();
39          bold.addItemListener( handler );
40          italic.addItemListener( handler );
41
42          setSize( 275, 100 );
43          setVisible( true );
44       }
45
46       // execute application
47       public static void main( String args[] )
48       {
49          CheckBoxTest application = new CheckBoxTest();
50
51          application.setDefaultCloseOperation(
52             JFrame.EXIT_ON_CLOSE );
53       }
54
55       // private inner class for ItemListener event handling
56       private class CheckBoxHandler implements ItemListener {
57          private int valBold = Font.PLAIN;
58          private int valItalic = Font.PLAIN;
59
60          // respond to checkbox events
61          public void itemStateChanged( ItemEvent event )
62          {
63             // process bold checkbox events
64             if ( event.getSource() == bold )
65
66                if ( event.getStateChange() == ItemEvent.SELECTED )
67                   valBold = Font.BOLD;
68                else
69                   valBold = Font.PLAIN;
70
71             // process italic checkbox events
72             if ( event.getSource() == italic )
73
74                if ( event.getStateChange() == ItemEvent.SELECTED )
75                   valItalic = Font.ITALIC;
76                else
77                   valItalic = Font.PLAIN;
78
```

Fig. 12.11 Program that creates two **JCheckBox** buttons (part 2 of 3).

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```
79            // set text field font
80            field.setFont(
81               new Font( "Serif", valBold + valItalic, 14 ) );
82         }
83
84      }  // end private inner class CheckBoxHandler
85
86   }  // end class CheckBoxTest
```

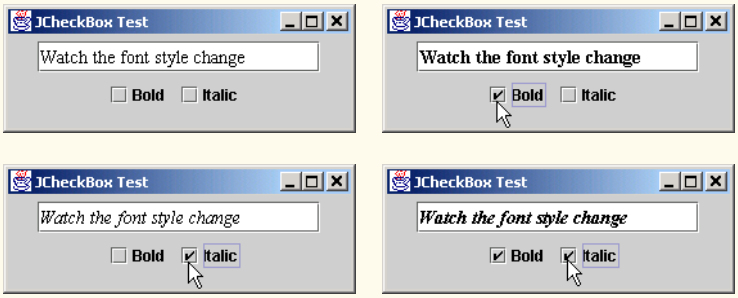

Fig. 12.11 Program that creates two **JCheckBox** buttons (part 3 of 3).

After the **JTextField** is created and initialized, line 27 sets the font of the **JTextField** to **Serif**, **PLAIN** style and **14**-point size. Next, the constructor creates two **JCheckBox** objects with lines 31 and 34. The **String** passed to the constructor is the *check box label* that appears to the right of the **JCheckBox** by default.

When the user clicks a **JCheckBox**, an **ItemEvent** occurs that can be handled by an **ItemListener** (any object of a class that implements interface **ItemListener**). An **ItemListener** must define method ***itemStateChanged***. In this example, the event handling is performed by an instance of inner class **CheckBoxHandler** (lines 56–84). Lines 38–40 create an instance of class **CheckBoxHandler** and register it with method ***addItemListener*** as the **ItemListener** for both the **bold** and **italic** **JCheckBox**es.

Method **itemStateChanged** (lines 61–82) is called when the user clicks either the **bold** or the **italic** checkbox. The method uses **event.getSource()** to determine which **JCheckBox** was clicked. If it was **JCheckBox** **bold**, the **if/else** structure at lines 66–69 uses **ItemEvent** method ***getStateChange*** to determine the state of the button (**ItemEvent.SELECTED** or **ItemEvent.DESELECTED**). If the state is selected, integer **valBold** is assigned **Font.BOLD**; otherwise, **valBold** is assigned **Font.PLAIN**. A similar **if/else** structure is executed if **JCheckBox** **italic** is clicked. If the **italic** state is selected, integer **valItalic** is assigned **Font.ITALIC**; otherwise, **valItalic** is assigned **Font.PLAIN**. The sum of **valBold** and **valItalic** is used at lines 80–81 as the style of the new font for the **JTextField**.

Radio buttons (defined with class ***JRadioButton***) are similar to check boxes in that they have two states—*selected* and *not selected* (also called *deselected*). However, radio buttons normally appear as a *group* in which only one radio button can be selected at a time. Selecting a different radio button in the group automatically forces all other radio buttons in the group to be deselected. Radio buttons are used to represent a set of *mutually exclusive*

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options (i.e., multiple options in the group would not be selected at the same time). The logical relationship between radio buttons is maintained by a ***ButtonGroup*** object (package **javax.swing**). The **ButtonGroup** object itself is not a GUI component. Therefore, a **ButtonGroup** object is not displayed in a user interface. Rather, the individual **JRadioButton** objects from the group are displayed in the GUI.

Common Programming Error 12.5

*Adding a **ButtonGroup** object (or an object of any other class that does not derive from **Component**) to a container is a syntax error.*

The application of Fig. 12.12 is similar to the preceding program. The user can alter the font style of a **JTextField**'s text. The program uses radio buttons that permit only a single font style in the group to be selected at a time.

```
1  // Fig. 12.12: RadioButtonTest.java
2  // Creating radio buttons using ButtonGroup and JRadioButton.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class RadioButtonTest extends JFrame {
12    private JTextField field;
13    private Font plainFont, boldFont, italicFont, boldItalicFont;
14    private JRadioButton plainButton, boldButton, italicButton,
15       boldItalicButton;
16    private ButtonGroup radioGroup;
17
18    // create GUI and fonts
19    public RadioButtonTest()
20    {
21       super( "RadioButton Test" );
22
23       // get content pane and set its layout
24       Container container = getContentPane();
25       container.setLayout( new FlowLayout() );
26
27       // set up JTextField
28       field =
29          new JTextField( "Watch the font style change", 25 );
30       container.add( field );
31
32       // create radio buttons
33       plainButton = new JRadioButton( "Plain", true );
34       container.add( plainButton );
35
36       boldButton = new JRadioButton( "Bold", false);
37       container.add( boldButton );
```

Fig. 12.12 Creating and manipulating radio button (part 1 of 3).

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```
38
39          italicButton = new JRadioButton( "Italic", false );
40          container.add( italicButton );
41
42          boldItalicButton = new JRadioButton(
43             "Bold/Italic", false );
44          container.add( boldItalicButton );
45
46          // register events for JRadioButtons
47          RadioButtonHandler handler = new RadioButtonHandler();
48          plainButton.addItemListener( handler );
49          boldButton.addItemListener( handler );
50          italicButton.addItemListener( handler );
51          boldItalicButton.addItemListener( handler );
52
53          // create logical relationship between JRadioButtons
54          radioGroup = new ButtonGroup();
55          radioGroup.add( plainButton );
56          radioGroup.add( boldButton );
57          radioGroup.add( italicButton );
58          radioGroup.add( boldItalicButton );
59
60          // create font objects
61          plainFont = new Font( "Serif", Font.PLAIN, 14 );
62          boldFont = new Font( "Serif", Font.BOLD, 14 );
63          italicFont = new Font( "Serif", Font.ITALIC, 14 );
64          boldItalicFont =
65             new Font( "Serif", Font.BOLD + Font.ITALIC, 14 );
66          field.setFont( plainFont );
67
68          setSize( 300, 100 );
69          setVisible( true );
70       }
71
72       // execute application
73       public static void main( String args[] )
74       {
75          RadioButtonTest application = new RadioButtonTest();
76
77          application.setDefaultCloseOperation(
78             JFrame.EXIT_ON_CLOSE );
79       }
80
81       // private inner class to handle radio button events
82       private class RadioButtonHandler implements ItemListener {
83
84          // handle radio button events
85          public void itemStateChanged( ItemEvent event )
86          {
87             // user clicked plainButton
88             if ( event.getSource() == plainButton )
89                field.setFont( plainFont );
90
```

Fig. 12.12 Creating and manipulating radio button (part 2 of 3).

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```
91             // user clicked boldButton
92             else if ( event.getSource() == boldButton )
93                field.setFont( boldFont );
94
95             // user clicked italicButton
96             else if ( event.getSource() == italicButton )
97                field.setFont( italicFont );
98
99             // user clicked boldItalicButton
100            else if ( event.getSource() == boldItalicButton )
101               field.setFont( boldItalicFont );
102         }
103
104      }  // end private inner class RadioButtonHandler
105
106   }  // end class RadioButtonTest
```

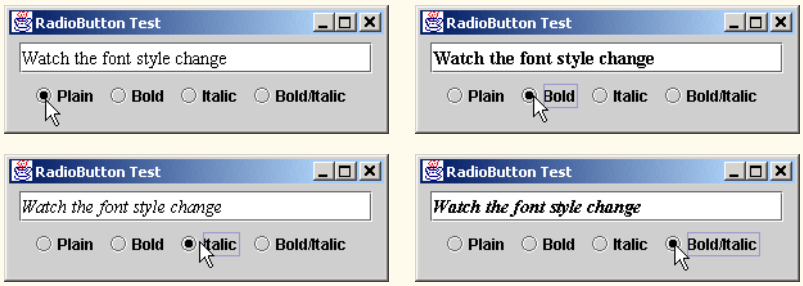

Fig. 12.12 Creating and manipulating radio button (part 3 of 3).

Lines 33–44 in the constructor define each **JRadioButton** object and add it to the application window's content pane. Each **JRadioButton** is initialized with a constructor call like line 33. This constructor supplies the label that appears to the right of the **JRadioButton** by default and the initial state of the **JRadioButton**. A **true** second argument indicates that the **JRadioButton** should appear selected when it is displayed.

JRadioButtons, like **JCheckBox**es, generate **ItemEvent**s when they are clicked. Lines 47–51 create an instance of inner class **RadioButtonHandler** (defined at lines 82–104) and register it to handle the **ItemEvent** generated when the user clicks any one of the **JRadioButton**s.

Line 54 instantiates a **ButtonGroup** object and assigns it to reference **radioGroup**. This object is the "glue" that binds the four **JRadioButton** objects together to form the logical relationship that allows only one of the four buttons to be selected at a time. Lines 55–58 use **ButtonGroup** method ***add*** to associate each of the **JRadioButton**s with **radioGroup**. If more than one selected **JRadioButton** object is added to the group, the first selected **JRadioButton** added will be selected when the GUI is displayed.

Class **RadioButtonHandler** (line 82–104) implements interface **ItemListener** so it can handle item events generated by the **JRadioButton**s. Each **JRadioButton** in the program has an instance of this class (**handler**) registered as its **ItemListener**. When the user clicks a **JRadioButton**, **radioGroup** turns off the previously selected **JRadioButton** and method **itemStateChanged** (line 85–102)

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executes. The method determines which **JRadioButton** was clicked using method **getSource** (inherited indirectly from **EventObject** into **ItemEvent**), then sets the font in the **JTextField** to one of the **Font** objects created in the constructor.

12.8 JComboBox

A *combo box* (sometimes called a *drop-down list*) provides a list of items from which the user can make a selection. Combo boxes are implemented with class ***JComboBox***, which inherits from class **JComponent**. **JComboBox**es generate **ItemEvent**s like **JCheckBox**es and **JRadioButton**s.

The application of Fig. 12.13 uses a **JComboBox** to provide a list of four image file names. When an image file name is selected, the corresponding image is displayed as an **Icon** on a **JLabel**. The screen captures for this program show the **JComboBox** list after the selection was made to illustrate which image file name was selected.

Lines 17–19 declare and initialize array icons with four new **ImageIcon** objects. **String** array **names** (defined on lines 15–16) contains the names of the four image files that are stored in the same directory as the application.

Line 31 creates a **JComboBox** object, using the **String**s in array **names** as the elements in the list. A numeric *index* keeps track of the ordering of items in the **JComboBox**. The first item is added at index 0; the next item is added at index 1, and so forth. The first item added to a **JComboBox** appears as the currently selected item when the **JComboBox** is displayed. Other items are selected by clicking the **JComboBox**. When clicked, the **JComboBox** expands into a list from which the user can make a selection.

Line 32 uses **JComboBox** method ***setMaximumRowCount*** to set the maximum number of elements that are displayed when the user clicks the **JComboBox**. If there are more items in the **JComboBox** than the maximum number of elements that are displayed, the **JComboBox** automatically provides a *scrollbar* (see the first screen capture) that allows the user to view all the elements in the list. The user can click the *scroll arrows* at the top and bottom of the scrollbar to move up and down through the list one element at a time, or the user can drag the *scroll box* in the middle of the scrollbar up and down to move through the list. To drag the scroll box, hold the mouse button down with the mouse cursor on the scroll box and move the mouse.

```
1  // Fig. 12.13: ComboBoxTest.java
2  // Using a JComboBox to select an image to display.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class ComboBoxTest extends JFrame {
12    private JComboBox imagesComboBox;
13    private JLabel label;
14
```

Fig. 12.13 Program that uses a **JComboBox** to select an icon (part 1 of 3).

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```
15    private String names[] =
16       { "bug1.gif", "bug2.gif",  "travelbug.gif", "buganim.gif" };
17    private Icon icons[] = { new ImageIcon( names[ 0 ] ),
18       new ImageIcon( names[ 1 ] ), new ImageIcon( names[ 2 ] ),
19       new ImageIcon( names[ 3 ] ) };
20
21    // set up GUI
22    public ComboBoxTest()
23    {
24       super( "Testing JComboBox" );
25
26       // get content pane and set its layout
27       Container container = getContentPane();
28       container.setLayout( new FlowLayout() );
29
30       // set up JComboBox and register its event handler
31       imagesComboBox = new JComboBox( names );
32       imagesComboBox.setMaximumRowCount( 3 );
33
34       imagesComboBox.addItemListener(
35
36          // anonymous inner class to handle JComboBox events
37          new ItemListener() {
38
39             // handle JComboBox event
40             public void itemStateChanged( ItemEvent event )
41             {
42                // determine whether check box selected
43                if ( event.getStateChange() == ItemEvent.SELECTED )
44                   label.setIcon( icons[
45                      imagesComboBox.getSelectedIndex() ] );
46             }
47
48          }  // end anonymous inner class
49
50       ); // end call to addItemListener
51
52       container.add( imagesComboBox );
53
54       // set up JLabel to display ImageIcons
55       label = new JLabel( icons[ 0 ] );
56       container.add( label );
57
58       setSize( 350, 100 );
59       setVisible( true );
60    }
61
62    // execute application
63    public static void main( String args[] )
64    {
65       ComboBoxTest application = new ComboBoxTest();
66
```

Fig. 12.13 Program that uses a **JComboBox** to select an icon (part 2 of 3).

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```
67          application.setDefaultCloseOperation(
68             JFrame.EXIT_ON_CLOSE );
69       }
70
71    }  // end class ComboBoxTest
```

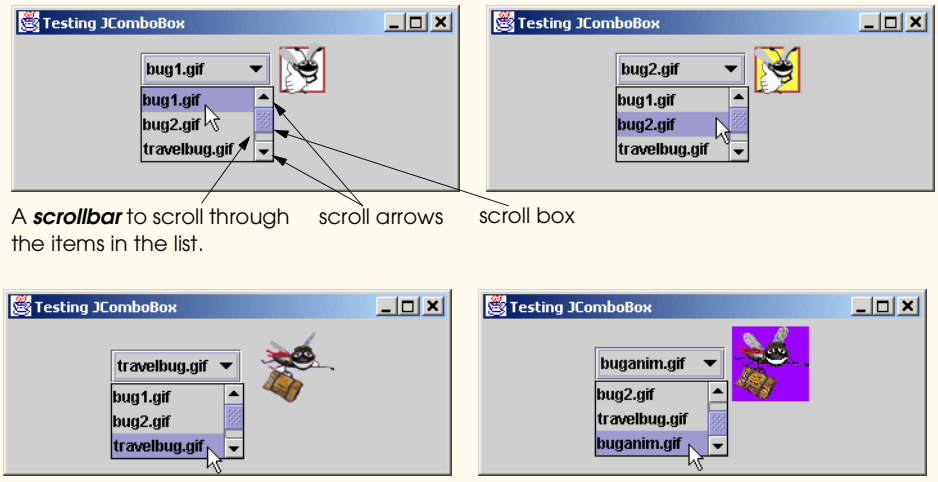

Fig. 12.13 Program that uses a **JComboBox** to select an icon (part 3 of 3).

Look-and-Feel Observation 12.7

Set the maximum row count for a ***JComboBox*** *to a number of rows that prevents the list from expanding outside the bounds of the window or applet in which it is used. This will ensure that the list displays correctly when it is expanded by the user.*

Lines 34–50 register an instance of an anonymous inner class that implements **ItemListener** as the listener for **JComboBox images**. When the user makes a selection from **images**, method **itemStateChanged** (line 40–46) sets the **Icon** for **label**. The **Icon** is selected from array **icons** by determining the index number of the selected item in the **JComboBox** with method ***getSelectedIndex*** in line 45. Note that line 43 changes the icon only for a selected item. The reason for the **if** structure here is that for each item that is selected from a **JComboBox**, another item is deselected. Thus, two events occur for each item selected. We wish to display only the icon for the item the user just selected.

12.9 JList

A *list* displays a series of items from which the user may select one or more items. Lists are created with class **JList**, which inherits from class **JComponent**. Class **JList** supports *single-selection lists* (i.e., lists that allow only one item to be selected at a time) and *multiple-selection lists* (lists that allow any number of items to be selected). In this section, we discuss single-selection lists.

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The application of Fig. 12.14 creates a **JList** of 13 colors. When a color name is clicked in the **JList**, a ***ListSelectionEvent*** occurs and the application window content pane's background color changes.

```
1  // Fig. 12.14: ListTest.java
2  // Selecting colors from a JList.
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9  import javax.swing.event.*;
10
11 public class ListTest extends JFrame {
12    private JList colorList;
13    private Container container;
14
15    private String colorNames[] = { "Black", "Blue", "Cyan",
16       "Dark Gray", "Gray", "Green", "Light Gray", "Magenta",
17       "Orange", "Pink", "Red", "White", "Yellow" };
18
19    private Color colors[] = { Color.black, Color.blue,
20       Color.cyan, Color.darkGray, Color.gray, Color.green,
21       Color.lightGray, Color.magenta, Color.orange, Color.pink,
22       Color.red, Color.white, Color.yellow };
23
24    // set up GUI
25    public ListTest()
26    {
27       super( "List Test" );
28
29       // get content pane and set its layout
30       container = getContentPane();
31       container.setLayout( new FlowLayout() );
32
33       // create a list with items in colorNames array
34       colorList = new JList( colorNames );
35       colorList.setVisibleRowCount( 5 );
36
37       // do not allow multiple selections
38       colorList.setSelectionMode(
39          ListSelectionModel.SINGLE_SELECTION );
40
41       // add a JScrollPane containing JList to content pane
42       container.add( new JScrollPane( colorList ) );
43
44       // set up event handler
45       colorList.addListSelectionListener(
46
47          // anonymous inner class for list selection events
48          new ListSelectionListener() {
```

Fig. 12.14 Selecting colors from a **JList** (part 1 of 2).

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```
49
50              // handle list selection events
51              public void valueChanged( ListSelectionEvent event )
52              {
53                 container.setBackground(
54                    colors[ colorList.getSelectedIndex() ] );
55              }
56
57           }  // end anonymous inner class
58
59        ); // end call to addListSelectionListener
60
61        setSize( 350, 150 );
62        setVisible( true );
63     }
64
65     // execute application
66     public static void main( String args[] )
67     {
68        ListTest application = new ListTest();
69
70        application.setDefaultCloseOperation(
71           JFrame.EXIT_ON_CLOSE );
72     }
73
74  }  // end class ListTest
```

Fig. 12.14 Selecting colors from a **JList** (part 2 of 2).

A **JList** object is instantiated at line 34 and assigned to reference **colorList** in the constructor. The argument to the **JList** constructor is the array of **Object**s (in this case **String**s) to display in the list. Line 35 uses **JList** method ***setVisibleRowCount*** to determine the number of items that are visible in the list.

Lines 38–39 use **JList** method ***setSelectionMode*** to specify the list *selection mode*. Class ***ListSelectionModel*** (package **javax.swing**) defines constants ***SINGLE_SELECTION***, ***SINGLE_INTERVAL_SELECTION*** and ***MULTIPLE_INTERVAL_SELECTION*** to specify a **JList**'s selection mode. A **SINGLE_SELECTION** list allows only one item to be selected at a time. A **SINGLE_INTERVAL_SELECTION** list is a multiple-selection list that allows several items in a contiguous range in the list to be selected. A **MULTIPLE_INTERVAL_SELECTION** list is a multiple-selection list that does not restrict the items that can be selected.

Unlike **JComboBox**, **JList**s *do not* provide a scrollbar if there are more items in the list than the number of visible rows. In this case, a ***JScrollPane*** object is used to provide

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the automatic scrolling capability for the **JList**. Line 42 adds a new instance of class ***JScrollPane*** to the content pane. The **JScrollPane** constructor receives as its argument the **JComponent** for which it will provide automatic scrolling functionality (in this case **JList colorList**). Notice in the screen captures that a scrollbar created by the **JScrollPane** appears at the right side of the **JList**. By default, the scrollbar appears only when the number of items in the **JList** exceeds the number of visible items.

Lines 45–59 use **JList** method ***addListSelectionListener*** to register an instance of an anonymous inner class that implements ***ListSelectionListener*** (defined in package **javax.swing.event**) as the listener for **JList colorList**. When the user makes a selection from **colorList**, method ***valueChanged*** (line 51–55) executes and sets the background color of the content pane with method ***setBackground*** (inherited from class **Component** into class **Container**). The color is selected from the array **colors** with the selected item's index in the list that is returned by **JList** method **getSelectedIndex** (as with arrays, **JList** indexing is zero based).

12.10 Multiple-Selection Lists

A *multiple-selection list* enables the user to select many items from a **JList**. A **SINGLE_INTERVAL_SELECTION** list allows selection of a contiguous range of items in the list by clicking the first item, then holding the *Shift* key while clicking the last item to select in the range. A **MULTIPLE_INTERVAL_SELECTION** list allows continuous range selection as described for a **SINGLE_INTERVAL_SELECTION** list and allows miscellaneous items to be selected by holding the *Ctrl* key (sometimes called to *Control* key)while clicking each item to select. To deselect an item, hold the *Ctrl* key while clicking the item a second time.

The application of Fig. 12.15 uses multiple-selection lists to copy items from one **JList** to another. One list is a **MULTIPLE_INTERVAL_SELECTION** list and the other is a **SINGLE_INTERVAL_SELECTION** list. When you execute the program, try using the selection techniques described above to select items in both lists.

```
1  // Fig. 12.15: MultipleSelection.java
2  // Copying items from one List to another.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class MultipleSelection extends JFrame {
12    private JList colorList, copyList;
13    private JButton copyButton;
14
15    private String colorNames[] = { "Black", "Blue", "Cyan",
16       "Dark Gray", "Gray", "Green", "Light Gray",
17       "Magenta", "Orange", "Pink", "Red", "White", "Yellow" };
```

Fig. 12.15 Using a multiple-selection **JList** (part 1 of 3).

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```
18
19    // set up GUI
20    public MultipleSelection()
21    {
22       super( "Multiple Selection Lists" );
23
24       // get content pane and set its layout
25       Container container = getContentPane();
26       container.setLayout( new FlowLayout() );
27
28       // set up JList colorList
29       colorList = new JList( colorNames );
30       colorList.setVisibleRowCount( 5 );
31       colorList.setFixedCellHeight( 15 );
32       colorList.setSelectionMode(
33          ListSelectionModel.MULTIPLE_INTERVAL_SELECTION );
34       container.add( new JScrollPane( colorList ) );
35
36       // create copy button and register its listener
37       copyButton = new JButton( "Copy >>>" );
38
39       copyButton.addActionListener(
40
41          // anonymous inner class for button event
42          new ActionListener() {
43
44             // handle button event
45             public void actionPerformed( ActionEvent event )
46             {
47                // place selected values in copyList
48                copyList.setListData(
49                   colorList.getSelectedValues() );
50             }
51
52          }  // end anonymous inner class
53
54       ); // end call to addActionListener
55
56       container.add( copyButton );
57
58       // set up JList copyList
59       copyList = new JList( );
60       copyList.setVisibleRowCount( 5 );
61       copyList.setFixedCellWidth( 100 );
62       copyList.setFixedCellHeight( 15 );
63       copyList.setSelectionMode(
64          ListSelectionModel.SINGLE_INTERVAL_SELECTION );
65       container.add( new JScrollPane( copyList ) );
66
67       setSize( 300, 120 );
68       setVisible( true );
69    }
70
```

Fig. 12.15 Using a multiple-selection **`JList`** (part 2 of 3).

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```
71      // execute application
72      public static void main( String args[] )
73      {
74         MultipleSelection application = new MultipleSelection();
75
76         application.setDefaultCloseOperation(
77            JFrame.EXIT_ON_CLOSE );
78      }
79
80   }  // end class MultipleSelection
```

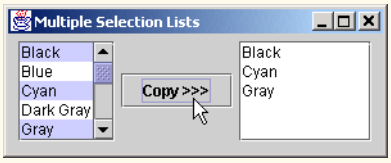

Fig. 12.15 Using a multiple-selection **JList** (part 3 of 3).

Line 29 creates **JList colorList** and initializes it with the **String**s in the array **colorNames**. Line 30 sets the number of visible rows in **colorList** to **5**. Line 31 uses **JList** method ***setFixedCellHeight*** to specify the height in pixels of each item in the **JList**. We do this to ensure that the rows in both **JLists** in the example have the same height. Lines 32–33 specify that **colorList** is a **MULTIPLE_INTERVAL_SELECTION** list. Line 34 adds a new **JScrollPane** containing **colorList** to the content pane. Lines 59–65 perform similar tasks for **JList copyList**, which is defined as a **SINGLE_INTERVAL_SELECTION** list. Line 61 uses **JList** method ***setFixedCellWidth*** to set **copyList**'s width to 100 pixels.

A multiple-selection list does not have a specific event associated with making multiple selections. Normally, an event generated by another GUI component (known as an *external event*) specifies when the multiple selections in a **JList** should be processed. In this example, the user clicks **JButton copyButton** to trigger the event that copies the selected items in **colorList** to **copyList**.

When the user clicks **copyButton**, method **actionPerformed** (line 45–50) is called. Lines 48–49 use **JList** method ***setListData*** to set the items displayed in **copyList**. Line 49 calls **colorList**'s method ***getSelectedValues***, which returns an array of **Object**s representing the selected items in **colorList**. In this example, the returned array is passed as the argument to **copyList**'s **setListData** method.

Many students ask how reference **copyList** can be used in line 48, when the program does not create the object to which it refers until Line 59. Remember that method **actionPerformed** at lines 45–50 does not execute until the user presses the **copyButton**, which cannot occur until after the call to the constructor completes. At that point in the program's execution, line 59 already has initialized **copyList** with a new **JList** object.

12.11 Mouse Event Handling

This section presents the ***MouseListener*** and ***MouseMotionListener*** event-listener interfaces for handling *mouse events*. Mouse events can be trapped for any GUI com-

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ponent that derives from **java.awt.Component**. The methods of interfaces **MouseListener** and **MouseMotionListener** are summarized in Figure 12.16.

Each of the mouse event handling methods takes a ***MouseEvent*** object as its argument. A **MouseEvent** object contains information about the mouse event that occurred, including the *x*- and *y*-coordinates of the location where the event occurred. The **MouseListener** and **MouseMotionListener** methods are called automatically when the mouse interacts with a **Component** if listener objects are registered for a particular **Component**. Method ***mousePressed*** is called when a mouse button is pressed with the mouse cursor over a component. Using methods and constants of class ***InputEvent*** (the superclass of **MouseEvent**), a program can determine which mouse button the user clicked. Method ***mouseClicked*** is called whenever a mouse button is released without moving the mouse after a **mousePressed** operation. Method ***mouseReleased*** is called whenever a mouse button is released. Method ***mouseEntered*** is called when the mouse cursor enters the physical boundaries of a **Component**. Method ***mouseExited*** is called when the mouse cursor leaves the physical boundaries of a **Component**. Method ***mouseDragged*** is called when the mouse button is pressed and held, and the mouse is moved (a process known as *dragging*). The **mouseDragged** event is preceded by a **mousePressed** event and followed by a **mouseReleased** event. Method ***mouseMoved*** is called when the mouse is moved with the mouse cursor over a component (and no mouse buttons pressed).

MouseListener and MouseMotionListener interface methods

Methods of interface ***MouseListener***

public void mousePressed(MouseEvent event)

Called when a mouse button is pressed with the mouse cursor on a component.

public void mouseClicked(MouseEvent event)

Called when a mouse button is pressed and released on a component without moving the mouse cursor.

public void mouseReleased(MouseEvent event)

Called when a mouse button is released after being pressed. This event is always preceded by a **mousePressed** event.

public void mouseEntered(MouseEvent event)

Called when the mouse cursor enters the bounds of a component.

public void mouseExited(MouseEvent event)

Called when the mouse cursor leaves the bounds of a component.

Methods of interface ***MouseMotionListener***

public void mouseDragged(MouseEvent event)

Called when the mouse button is pressed with the mouse cursor on a component and the mouse is moved. This event is always preceded by a call to **mousePressed**.

public void mouseMoved(MouseEvent event)

Called when the mouse is moved with the mouse cursor on a component.

Fig. 12.16 **MouseListener** and **MouseMotionListener** interface methods.

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Look-and-Feel Observation 12.8

Method calls to ***mouseDragged*** *are sent to the* ***MouseMotionListener*** *for the* ***Component*** *on which the drag operation started. Similarly, the* ***mouseReleased*** *method call is sent to the* ***MouseListener*** *for the* ***Component*** *on which the drag operation started.*

The **MouseTracker** application (Fig. 12.17) demonstrates the **MouseListener** and **MouseMotionListener** methods. The application class implements both interfaces so it can listen for its own mouse events. Note that all seven methods from these two interfaces must be defined by the programmer when a class implements both interfaces. The message dialog box in the sample output windows appears when the user moves the mouse into the application window.

```
1  // Fig. 12.17: MouseTracker.java
2  // Demonstrating mouse events.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class MouseTracker extends JFrame
12    implements MouseListener, MouseMotionListener {
13
14    private JLabel statusBar;
15
16    // set up GUI and register mouse event handlers
17    public MouseTracker()
18    {
19       super( "Demonstrating Mouse Events" );
20
21       statusBar = new JLabel();
22       getContentPane().add( statusBar, BorderLayout.SOUTH );
23
24       // application listens to its own mouse events
25       addMouseListener( this );
26       addMouseMotionListener( this );
27
28       setSize( 275, 100 );
29       setVisible( true );
30    }
31
32    // MouseListener event handlers
33
34    // handle event when mouse released immediately after press
35    public void mouseClicked( MouseEvent event )
36    {
37       statusBar.setText( "Clicked at [" + event.getX() +
38          ", " + event.getY() + "]" );
39    }
```

Fig. 12.17 Demonstrating mouse event handling (part 1 of 3).

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```
40
41     // handle event when mouse pressed
42     public void mousePressed( MouseEvent event )
43     {
44        statusBar.setText( "Pressed at [" + event.getX() +
45           ", " + event.getY() + "]" );
46     }
47
48     // handle event when mouse released after dragging
49     public void mouseReleased( MouseEvent event )
50     {
51        statusBar.setText( "Released at [" + event.getX() +
52           ", " + event.getY() + "]" );
53     }
54
55     // handle event when mouse enters area
56     public void mouseEntered( MouseEvent event )
57     {
58        JOptionPane.showMessageDialog( null, "Mouse in window" );
59     }
60
61     // handle event when mouse exits area
62     public void mouseExited( MouseEvent event )
63     {
64        statusBar.setText( "Mouse outside window" );
65     }
66
67     // MouseMotionListener event handlers
68
69     // handle event when user drags mouse with button pressed
70     public void mouseDragged( MouseEvent event )
71     {
72        statusBar.setText( "Dragged at [" + event.getX() +
73           ", " + event.getY() + "]" );
74     }
75
76     // handle event when user moves mouse
77     public void mouseMoved( MouseEvent event )
78     {
79        statusBar.setText( "Moved at [" + event.getX() +
80           ", " + event.getY() + "]" );
81     }
82
83     // execute application
84     public static void main( String args[] )
85     {
86        MouseTracker application = new MouseTracker();
87
88        application.setDefaultCloseOperation(
89           JFrame.EXIT_ON_CLOSE );
90     }
91
92  }  // end class MouseTracker
```

Fig. 12.17 Demonstrating mouse event handling (part 2 of 3).

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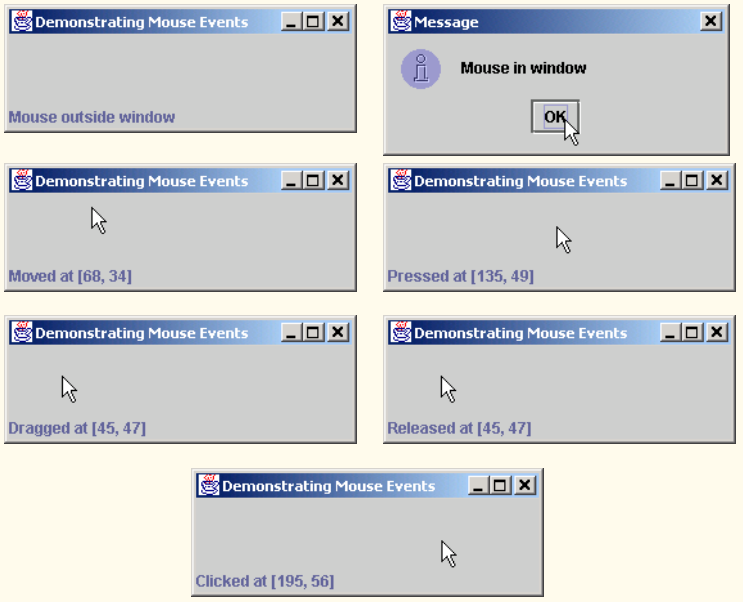

Fig. 12.17 Demonstrating mouse event handling (part 3 of 3).

Each mouse event results in a **`String`** displayed in **`JLabel statusBar`** at the bottom of the window.

Lines 21–22 in the constructor define **`JLabel statusBar`** and attach it to the content pane. Until now, each time we used the content pane, method **`setLayout`** was called to set the content pane's layout manager to a **`FlowLayout`**. This allowed the content pane to display the GUI components we attached to it from left to right. If the GUI components do not fit on one line, the **`FlowLayout`** creates additional lines to continue displaying the GUI components. Actually, the default layout manager is a ***`BorderLayout`*** that divides the content pane's area into five regions—north, south, east, west and center. Line 22 uses a new version of **`Container`** method **`add`** to attach **`statusBar`** to the region ***`BorderLayout.SOUTH`***, which extends across the entire bottom of the content pane. We discuss **`BorderLayout`** and several other layout managers in detail later in this chapter.

Lines 25–26 in the constructor register the **`MouseTracker`** window object as the listener for its own mouse events. Methods ***`addMouseListener`*** and ***`addMouseMotionListener`*** are **`Component`** methods that can be used to register mouse event listeners for an object of any class that extends **`Component`**.

When the mouse enters or exits the application area, method **`mouseEntered`** (lines 56–59) and method **`mouseExited`** (lines 62–65) are called, respectively. Method **`mouseExited`** displays a message in **`statusBar`** indicating that the mouse is outside the application (see the first sample output window). Method **`mouseEntered`** displays a message dialog box indicating that the mouse entered the application window. [Note: Be sure to press *Enter* to dismiss the message dialog, rather than using the mouse. If you use the mouse to dismiss the dialog, when you move the mouse over the window again, **`mouseEntered`** redisplays the dialog. This will prevent you from trying the other mouse events.]

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When any of the other five events occur, they display a message in **statusBar** that includes a **String** that represents the event that occurred and the coordinates where the mouse event occurred. The *x* and *y* coordinates of the mouse when the event occurred are obtained with **MouseEvent** methods ***getX*** and ***getY***, respectively.

12.12 Adapter Classes

Many of the event-listener interfaces provide multiple methods; **MouseListener** and **MouseMotionListener** are examples. It is not always desirable to define every method in an event-listener interface. For example, a program may only need the **mouseClicked** handler from interface **MouseListener** or the **mouseDragged** handler from **MouseMotionListener**. In our windowed applications (subclasses of **JFrame**) terminating the application has been handled with **windowClosing** from interface **WindowListener**, which actually specifies seven window-event-handling methods. For many of the listener interfaces that contain multiple methods, package **java.awt.event** and package **javax.swing.event** provide event-listener *adapter classes*. An adapter class implements an interface and provides a default implementation (with an empty method body) of every method in the interface. The **java.awt.event** adapter classes are shown in Fig. 12.18 along with the interfaces they implement.

The programmer can extend the adapter class to inherit the default implementation of every method, then override the method(s) needed for event handling. The default implementation of each method in the adapter class has an empty body. This is exactly what we have been doing in each application example that extends **JFrame** and defines method **windowClosing** to handle the closing of the window and termination of the application.

Software Engineering Observation 12.3

When a class implements an interface, the class has an "is a" relationship with that interface. All direct and indirect subclasses of that class inherit this relationship. Thus, an object of a class that extends an event adapter class is an *object of the corresponding event listener type (e.g., an object of a subclass of* ***MouseAdapter*** is a ***MouseListener****).*

Event adapter class	Implements interface
ComponentAdapter	**ComponentListener**
ContainerAdapter	**ContainerListener**
FocusAdapter	**FocusListener**
KeyAdapter	**KeyListener**
MouseAdapter	**MouseListener**
MouseMotionAdapter	**MouseMotionListener**
WindowAdapter	**WindowListener**

Fig. 12.18 Event adapter classes and the interfaces they implement.

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The **Painter** application of Fig. 12.19 uses the **mouseDragged** event handler to create a simple drawing program. The user can draw pictures with the mouse by dragging the mouse on the background of the window. This example does not use method **mouseMoved**, so our **MouseMotionListener** is defined as a subclass of **MouseMotionAdapter**. This class already defines both **mouseMoved** and **mouseDragged**, so we can simply override **mouseDragged** to provide the drawing functionality.

```
1  // Fig. 12.19: Painter.java
2  // Using class MouseMotionAdapter.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class Painter extends JFrame {
12    private int xValue = -10, yValue = -10;
13
14    // set up GUI and register mouse event handler
15    public Painter()
16    {
17       super( "A simple paint program" );
18
19       // create a label and place it in SOUTH of BorderLayout
20       getContentPane().add(
21          new Label( "Drag the mouse to draw" ),
22          BorderLayout.SOUTH );
23
24       addMouseMotionListener(
25
26          // anonymous inner class
27          new MouseMotionAdapter() {
28
29             // store drag coordinates and repaint
30             public void mouseDragged( MouseEvent event )
31             {
32                xValue = event.getX();
33                yValue = event.getY();
34                repaint();
35             }
36
37          }  // end anonymous inner class
38
39       ); // end call to addMouseMotionListener
40
41       setSize( 300, 150 );
42       setVisible( true );
43    }
44
```

Fig. 12.19 Program that demonstrates adapter classes (part 1 of 2).

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```
45     // draw oval in a 4-by-4 bounding box at the specified
46     // location on the window
47     public void paint( Graphics g )
48     {
49        // we purposely did not call super.paint( g ) here to
50        // prevent repainting
51
52        g.fillOval( xValue, yValue, 4, 4 );
53     }
54
55     // execute application
56     public static void main( String args[] )
57     {
58        Painter application = new Painter();
59
60        application.addWindowListener(
61
62           // adapter to handle only windowClosing event
63           new WindowAdapter() {
64
65              public void windowClosing( WindowEvent event )
66              {
67                 System.exit( 0 );
68              }
69
70           }  // end anonymous inner class
71
72        ); // end call to addWindowListener
73     }
74
75  }  // end class Painter
```

Fig. 12.19 Program that demonstrates adapter classes (part 2 of 2).

The instance variables **xValue** and **yValue** store the coordinates of the **mouseDragged** event. Initially, the coordinates are set outside the window area to prevent an oval from drawing on the background area in the first call to **paint** when the window is displayed. Lines 24–39 register a **MouseMotionListener** to listen for the window's mouse motion events (remember that a call to a method that is not preceded by a reference and a dot operator is really preceded by "**this.**", indicating that the method is called for the current instance of the class at execution time). Lines 27–37 define an anonymous inner class that extends class **MouseMotionAdapter** (which implements **MouseMotionListener**). The anonymous inner class inherits a default implementation of both method **mouseMoved** and method **mouseDragged**. Thus, the anonymous inner class already satisfies the requirement that in all methods an interface must be implemented. However,

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the default methods do nothing when they are called. So, we override method **mouseDragged** at lines 30–35 to capture the *x*- and *y*-coordinates of the mouse-dragged event and store them in instance variables **xValue** and **yValue**, then call **repaint** to initiate drawing the next oval on the background (performed by method **paint** at lines 47–53). Note that **paint** does not call the superclass version of **paint** inherited from **JFrame**. The superclass version normally clears the background of the window. Not calling the superclass version enables our program to keep all the ovals on the window at once. However, notice that if you cover the window with another window, only the last oval displayed still appears, because our program does not keep track of all the ovals displayed previously.

Lines 60–72 register a **WindowListener** to listen for the application window's window events (such as closing the window). Lines 63–70 define an anonymous inner class that extends class **WindowAdapter** (which implements **WindowListener**). The anonymous inner class inherits a default implementation of seven different window-event-handler methods. Thus, the anonymous inner class already satisfies the requirement that in all methods an interface must be implemented. However, the default methods do nothing when they are called. So, we override method **windowClosing** at lines 65–68 to terminate the application when the user clicks the application window's close box.

The **MouseDetails** application of Fig. 12.20 demonstrates how to determine the number of mouse clicks (i.e., the click count) and how to distinguish between the different mouse buttons. The event listener in this program is an object of inner class **MouseClickHandler** (lines 47–75) that extends **MouseAdapter** so we can define just the **mouseClicked** method we need in this example.

```
1  // Fig. 12.20: MouseDetails.java
2  // Demonstrating mouse clicks and
3  // distinguishing between mouse buttons.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class MouseDetails extends JFrame {
13    private int xPos, yPos;
14
15    // set title bar String, register mouse listener and size
16    // and show window
17    public MouseDetails()
18    {
19       super( "Mouse clicks and buttons" );
20
21       addMouseListener( new MouseClickHandler() );
22
23       setSize( 350, 150 );
24       setVisible( true );
25    }
```

Fig. 12.20 Distinguishing among left, center and right mouse-button clicks (part 1 of 3).

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```
26
27     // draw String at location where mouse was clicked
28     public void paint( Graphics g )
29     {
30        // call superclass's paint method
31        super.paint( g );
32
33        g.drawString( "Clicked @ [" + xPos + ", " + yPos + "]",
34           xPos, yPos );
35     }
36
37     // execute application
38     public static void main( String args[] )
39     {
40        MouseDetails application = new MouseDetails();
41
42        application.setDefaultCloseOperation(
43           JFrame.EXIT_ON_CLOSE );
44     }
45
46     // inner class to handle mouse events
47     private class MouseClickHandler extends MouseAdapter {
48
49        // handle mouse click event and determine which mouse
50        // button was pressed
51        public void mouseClicked( MouseEvent event )
52        {
53           xPos = event.getX();
54           yPos = event.getY();
55
56           String title =
57              "Clicked " + event.getClickCount() + " time(s)";
58
59           // right mouse button
60           if ( event.isMetaDown() )
61              title += " with right mouse button";
62
63           // middle mouse button
64           else if ( event.isAltDown() )
65              title += " with center mouse button";
66
67           // left mouse button
68           else
69              title += " with left mouse button";
70
71           setTitle( title );  // set title bar of window
72           repaint();
73        }
74
75     }  // end private inner class MouseClickHandler
76
77  }  // end class MouseDetails
```

Fig. 12.20 Distinguishing among left, center and right mouse-button clicks (part 2 of 3).

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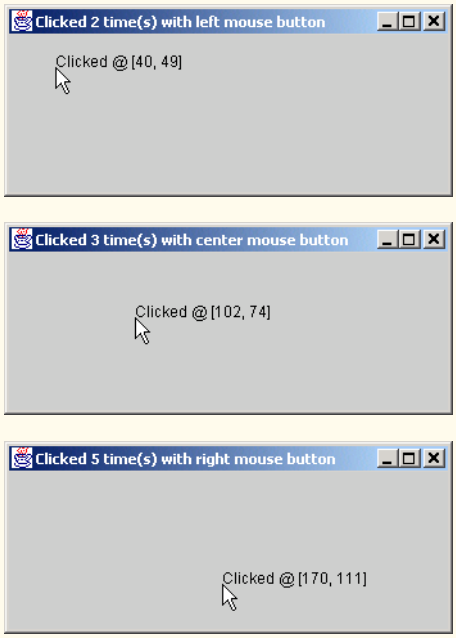

Fig. 12.20 Distinguishing among left, center and right mouse-button clicks (part 3 of 3).

A user of a Java program may be on a system with a one-, two- or three-button mouse. Java provides a mechanism to distinguish among mouse buttons. Class **`MouseEvent`** inherits several methods from class **`InputEvent`** that can distinguish between mouse buttons on a multi-button mouse or can mimic a multi-button mouse with a combined keystroke and mouse-button click. Figure 12.21 shows the **`InputEvent`** methods used to distinguish between mouse-button clicks. Java assumes that every mouse contains a left mouse button. Thus, it is simple to test for a left-mouse-button click. However, users with a one- or two-button mouse must use a combination of pressing keys on the keyboard and clicking the mouse at the same time to simulate the missing buttons on the mouse. In the case of a one- or two-button mouse, this program assumes that the center mouse button is clicked if the user holds the *Alt* key and clicks the left mouse button on a two-button mouse or the only mouse button on a one-button mouse. In the case of a one-button mouse, this program assumes that the right mouse button is clicked if the user holds the *Meta* key and clicks the mouse button.

Method **`mouseClicked`** (lines 51–73) first captures the coordinates where the event occurred and stores them in instance variables **`xPos`** and **`yPos`** of class **`MouseDetails`**. Lines 56–57 create a string containing the number of mouse clicks (as returned by **`MouseEvent`** method ***`getClickCount`*** at line 57). The nested **`if`** structure at lines 60–69 uses methods **`isMetaDown`** and **`isAltDown`** to determine which mouse button the user clicked and appends an appropriate string to **`title`** in each case. The resulting string is displayed in the title bar of the window with method ***`setTitle`*** (inherited into class **`JFrame`** from class **`Frame`**) at line 71. Line 72 calls **`repaint`** to initiate a call to **`paint`** to draw a string at the location where the user clicked the mouse.

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InputEvent method	Description
`isMetaDown()`	This method returns **`true`** when the user clicks the right mouse button on a mouse with two or three buttons. To simulate a right-mouse-button click on a one-button mouse, the user can press the *Meta* key on the keyboard and click the mouse button.
`isAltDown()`	This method returns **`true`** when the user clicks the middle mouse button on a mouse with three buttons. To simulate a middle-mouse-button click on a one- or two-button mouse, the user can press the *Alt* key on the keyboard and click the mouse button.

Fig. 12.21 **`InputEvent`** methods that help distinguish among left-, center- and right-mouse-button clicks .

12.13 Keyboard Event Handling

This section presents the **`KeyListener`** event-listener interface for handling *key events*. Key events are generated when keys on the keyboard are pressed and released. A class that implements **`KeyListener`** must provide definitions for methods ***`keyPressed`***, ***`keyReleased`*** and ***`keyTyped`***, each of which receives a ***`KeyEvent`*** as its argument. Class **`KeyEvent`** is a subclass of **`InputEvent`**. Method **`keyPressed`** is called in response to pressing any key. Method **`keyTyped`** is called in response to pressing any key that is not an *action key* (e.g., an arrow key, *Home*, *End*, *Page Up*, *Page Down*, a function key, *Num Lock*, *Print Screen*, *Scroll Lock*, *Caps Lock* and *Pause*). Method **`keyReleased`** is called when the key is released after any **`keyPressed`** or **`keyTyped`** event.

Figure 12.22 demonstrates the **`KeyListener`** methods. Class **`KeyDemo`** implements the **`KeyListener`** interface, so all three methods are defined in the application.

```
1  // Fig. 12.22: KeyDemo.java
2  // Demonstrating keystroke events.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class KeyDemo extends JFrame implements KeyListener {
12    private String line1 = "", line2 = "";
13    private String line3 = "";
14    private JTextArea textArea;
15
16    // set up GUI
17    public KeyDemo()
18    {
19       super( "Demonstrating Keystroke Events" );
```

Fig. 12.22 Demonstrating key event-handling (part 1 of 3).

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```
20
21          // set up JTextArea
22          textArea = new JTextArea( 10, 15 );
23          textArea.setText( "Press any key on the keyboard..." );
24          textArea.setEnabled( false );
25          getContentPane().add( textArea );
26
27          // allow frame to process Key events
28          addKeyListener( this );
29
30          setSize( 350, 100 );
31          setVisible( true );
32       }
33
34       // handle press of any key
35       public void keyPressed( KeyEvent event )
36       {
37          line1 = "Key pressed: " +
38             event.getKeyText( event.getKeyCode() );
39          setLines2and3( event );
40       }
41
42       // handle release of any key
43       public void keyReleased( KeyEvent event )
44       {
45          line1 = "Key released: " +
46             event.getKeyText( event.getKeyCode() );
47          setLines2and3( event );
48       }
49
50       // handle press of an action key
51       public void keyTyped( KeyEvent event )
52       {
53          line1 = "Key typed: " + event.getKeyChar();
54          setLines2and3( event );
55       }
56
57       // set second and third lines of output
58       private void setLines2and3( KeyEvent event )
59       {
60          line2 = "This key is " +
61             ( event.isActionKey() ? "" : "not " ) +
62             "an action key";
63
64          String temp =
65             event.getKeyModifiersText( event.getModifiers() );
66
67          line3 = "Modifier keys pressed: " +
68             ( temp.equals( "" ) ? "none" : temp );
69
70          textArea.setText(
71             line1 + "\n" + line2 + "\n" + line3 + "\n" );
72       }
```

Fig. 12.22 Demonstrating key event-handling (part 2 of 3).

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```
73
74       // execute application
75       public static void main( String args[] )
76       {
77          KeyDemo application = new KeyDemo();
78
79          application.setDefaultCloseOperation(
80             JFrame.EXIT_ON_CLOSE );
81       }
82
83    }  // end class KeyDemo
```

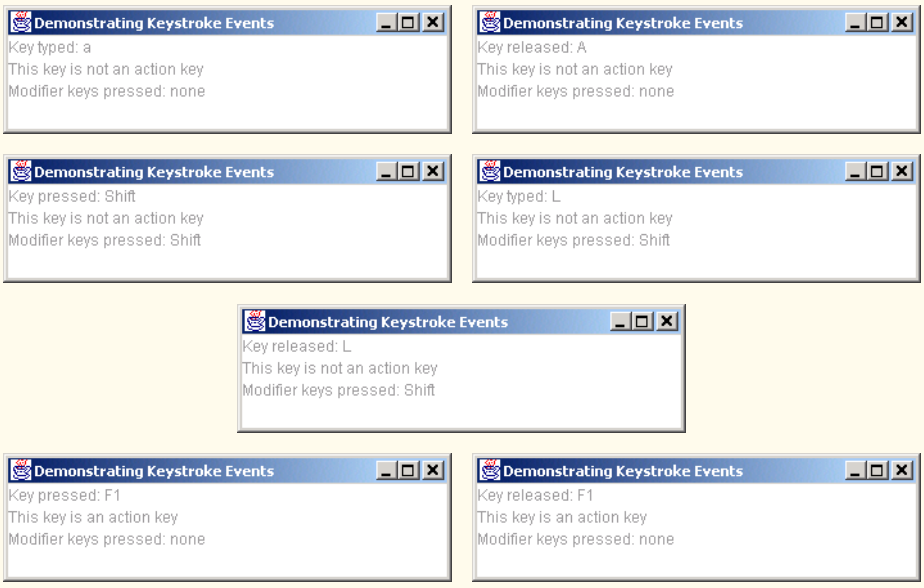

Fig. 12.22 Demonstrating key event-handling (part 3 of 3).

The constructor (lines 17–32) registers the application to handle its own key events with method ***addKeyListener*** at line 28. Method **addKeyListener** is defined in class **Component**, so every subclass of **Component** can notify **KeyListener**s of key events for that **Component**.

Line 25 in the constructor adds **JTextArea textArea** (where the program's output is displayed) to the content pane. Notice, in the screen captures, that **textArea** occupies the entire window. This is due to the content pane's default **BorderLayout** (discussed in Section 12.14.2 and demonstrated in Fig. 12.25). When a single **Component** is added to a **BorderLayout**, the **Component** occupies the entire **Container**.

Methods **keyPressed** (lines 35–40) and **keyReleased** (lines 43–48) use **KeyEvent** method ***getKeyCode*** to get the *virtual key code* of the key that was pressed. Class **KeyEvent** maintains a set of constants—the virtual key code constants—that represent every key on the keyboard. These constants can be compared with the return value of **getKeyCode** to test for individual keys on the keyboard. The value returned by **getKeyCode** is passed to **KeyEvent** method ***getKeyText***, which returns a **String** con-

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taining the name of the key that was pressed. For a complete list of virtual key constants, see the on-line documentation for class **KeyEvent** (package **java.awt.event**). Method **keyTyped** (lines 51–55) uses **KeyEvent** method ***getKeyChar*** to get the Unicode value of the character typed.

All three event handling methods finish by calling method **setLines2and3** (lines 58–72) and passing it the **KeyEvent** object. This method uses **KeyEvent** method ***isActionKey*** to determine if the key in the event was an action key. Also, **InputEvent** method ***getModifiers*** is called to determine if any modifier keys (such as *Shift*, *Alt* and *Ctrl*) were pressed when the key event occurred. The result of this method is passed to **KeyEvent** method ***getKeyModifiersText***, which produces a string containing the names of the pressed modifier keys.

[Note: If you need to test for a specific key on the keyboard, class **KeyEvent** provides a *key constant* for every key on the keyboard. These constants can be used from the key event handlers to determine if a particular key was pressed. Also, to determine whether the *Alt*, *Ctrl*, *Meta* and *Shift* keys are pressed individually, **InputEvent** methods **isAltDown**, ***isControlDown***, **isMetaDown** and ***isShiftDown*** each return a **boolean** indicating if the particular key was pressed during the key event.]

12.14 Layout Managers

Layout managers are provided to arrange GUI components on a container for presentation purposes. The layout managers provide basic layout capabilities that are easier to use than determining the exact position and size of every GUI component. This enables the programmer to concentrate on the basic "look and feel" and lets the layout managers process most of the layout details.

Look-and-Feel Observation 12.9

Most Java programming environments provide GUI design tools that help a programmer graphically design a GUI, then automatically write Java code to create the GUI.

Some GUI designers also allow the programmer to use the layout managers described here and in Chapter 13. Figure 12.23 summarizes the layout managers presented in this chapter. Other layout managers are discussed in Chapter 13.

Layout manager	Description
FlowLayout	Default for **java.awt.Applet**, **java.awt.Panel** and **javax.swing.JPanel**. Places components sequentially (left to right) in the order they were added. It is also possible to specify the order of the components using the **Container** method **add** that takes a **Component** and an integer index position as arguments.
BorderLayout	Default for the content panes of **JFrame**s (and other windows) and **JApplet**s. Arranges the components into five areas: North, South, East, West and Center.
GridLayout	Arranges the components into rows and columns.

Fig. 12.23 Layout managers.

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Most previous applet and application examples in which we created our own GUI used layout manager ***FlowLayout***. Class **FlowLayout** inherits from class **Object** and implements interface ***LayoutManager***, which defines the methods a layout manager uses to arrange and size GUI components on a container.

12.14.1 FlowLayout

FlowLayout is the most basic layout manager. GUI components are placed on a container from left to right in the order in which they are added to the container. When the edge of the container is reached, components are continued on the next line. Class **FlowLayout** allows GUI components to be *left-aligned*, *centered* (the default) and *right-aligned*.

The application of Fig. 12.24 creates three **JButton** objects and adds them to the application, using a **FlowLayout** layout manager. The components are automatically center-aligned. When the user clicks **Left**, the alignment for the layout manager is changed to a left-aligned **FlowLayout**. When the user clicks **Right**, the alignment for the layout manager is changed to a right-aligned **FlowLayout**. When the user clicks **Center**, the alignment for the layout manager is changed to a center-aligned **FlowLayout**. Each button has its own event handler that is defined with an inner class that implements **ActionListener**. The sample output windows show each of the **FlowLayout** alignments. Also, the last sample output window shows the centered alignment after the window has been resized to a smaller width. Notice that the button **Right** now appears on a new line.

```
1  // Fig. 12.24: FlowLayoutDemo.java
2  // Demonstrating FlowLayout alignments.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class FlowLayoutDemo extends JFrame {
12    private JButton leftButton, centerButton, rightButton;
13    private Container container;
14    private FlowLayout layout;
15
16    // set up GUI and register button listeners
17    public FlowLayoutDemo()
18    {
19       super( "FlowLayout Demo" );
20
21       layout = new FlowLayout();
22
23       // get content pane and set its layout
24       container = getContentPane();
25       container.setLayout( layout );
26
```

Fig. 12.24 Program that demonstrates components in **FlowLayout** (part 1 of 3).

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```
27          // set up leftButton and register listener
28          leftButton = new JButton( "Left" );
29
30          leftButton.addActionListener(
31
32             // anonymous inner class
33             new ActionListener() {
34
35                // process leftButton event
36                public void actionPerformed( ActionEvent event )
37                {
38                   layout.setAlignment( FlowLayout.LEFT );
39
40                   // re-align attached components
41                   layout.layoutContainer( container );
42                }
43
44             }  // end anonymous inner class
45
46          ); // end call to addActionListener
47
48          container.add( leftButton );
49
50          // set up centerButton and register listener
51          centerButton = new JButton( "Center" );
52
53          centerButton.addActionListener(
54
55             // anonymous inner class
56             new ActionListener() {
57
58                // process centerButton event
59                public void actionPerformed( ActionEvent event )
60                {
61                   layout.setAlignment( FlowLayout.CENTER );
62
63                   // re-align attached components
64                   layout.layoutContainer( container );
65                }
66             }
67          );
68
69          container.add( centerButton );
70
71          // set up rightButton and register listener
72          rightButton = new JButton( "Right" );
73
74          rightButton.addActionListener(
75
76             // anonymous inner class
77             new ActionListener() {
78
```

Fig. 12.24 Program that demonstrates components in **`FlowLayout`** (part 2 of 3).

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```
79                // process rightButton event
80                public void actionPerformed( ActionEvent event )
81                {
82                   layout.setAlignment( FlowLayout.RIGHT );
83
84                   // re-align attached components
85                   layout.layoutContainer( container );
86                }
87             }
88          );
89
90          container.add( rightButton );
91
92          setSize( 300, 75 );
93          setVisible( true );
94       }
95
96       // execute application
97       public static void main( String args[] )
98       {
99          FlowLayoutDemo application = new FlowLayoutDemo();
100
101         application.setDefaultCloseOperation(
102            JFrame.EXIT_ON_CLOSE );
103      }
104
105   }  // end class FlowLayoutDemo
```

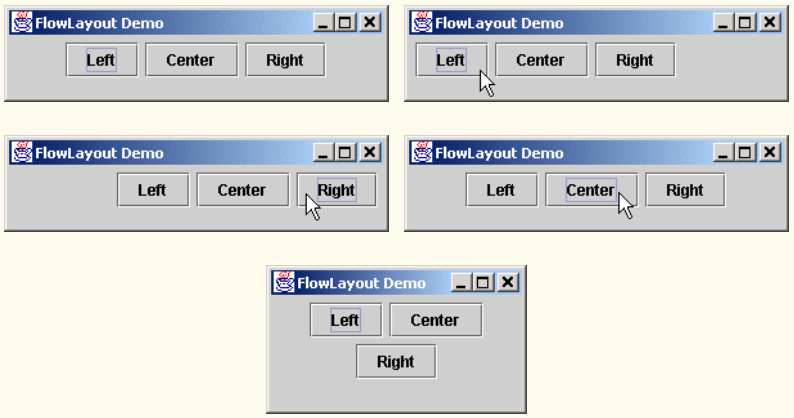

Fig. 12.24 Program that demonstrates components in **`FlowLayout`** (part 3 of 3).

As seen previously, a container's layout is set with method ***`setLayout`*** of class **`Container`**. Line 25 sets the content pane's layout manager to the **`FlowLayout`** defined at line 21. Normally, the layout is set before any GUI components are added to a container.

Look-and-Feel Observation 12.10

Each container can have only one layout manager at a time. (Separate containers in the same program can have different layout managers.)

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Each button's **actionPerformed** event handler executes two statements. For example, line 38 in method **actionPerformed** for button **left** uses **FlowLayout** method ***setAlignment*** to change the alignment for the **FlowLayout** to a left-aligned (***FlowLayout.LEFT***) **FlowLayout**. Line 41 uses **LayoutManager** interface method ***layoutContainer*** to specify that the content pane should be rearranged based on the adjusted layout.

According to which button was clicked, the **actionPerformed** method for each button sets the **FlowLayout**'s alignment to ***FlowLayout.LEFT***, ***FlowLayout.CENTER*** or ***FlowLayout.RIGHT***.

12.14.2 BorderLayout

The ***BorderLayout*** layout manager (the default layout manager for the content pane) arranges components into five regions: ***NORTH***, ***SOUTH***, ***EAST***, ***WEST*** and ***CENTER*** (North corresponds to the top of the container). Class **BorderLayout** inherits from **Object** and implements interface ***LayoutManager2*** (a subinterface of **LayoutManager** that adds several methods for enhanced layout processing).

Up to five components can be added directly to a **BorderLayout**—one for each region. The component placed in each region can be a container to which other components are attached. The components placed in the **NORTH** and **SOUTH** regions extend horizontally to the sides of the container and are as tall as the components placed in those regions. The **EAST** and **WEST** regions expand vertically between the **NORTH** and **SOUTH** regions and are as wide as the components placed in those regions. The component placed in the **CENTER** region expands to take all remaining space in the layout (this is the reason the **JTextArea** in Fig. 12.22 occupies the entire window). If all five regions are occupied, the entire container's space is covered by GUI components. If the **NORTH** or **SOUTH** region is not occupied, the GUI components in the **EAST**, **CENTER** and **WEST** regions expand vertically to fill the remaining space. If the **EAST** or **WEST** region is not occupied, the GUI component in the **CENTER** region expands horizontally to fill the remaining space. If the **CENTER** region is not occupied, the area is left empty—the other GUI components do not expand to fill the remaining space.

The application of Fig. 12.25 demonstrates the **BorderLayout** layout manager by using five **JButton**s.

```
1  // Fig. 12.25: BorderLayoutDemo.java
2  // Demonstrating BorderLayout.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class BorderLayoutDemo extends JFrame
12    implements ActionListener {
13
```

Fig. 12.25 Demonstrating components in **BorderLayout** (part 1 of 3).

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```
14    private JButton buttons[];
15    private String names[] = { "Hide North", "Hide South",
16       "Hide East", "Hide West", "Hide Center" };
17    private BorderLayout layout;
18
19    // set up GUI and event handling
20    public BorderLayoutDemo()
21    {
22       super( "BorderLayout Demo" );
23
24       layout = new BorderLayout( 5, 5 );
25
26       // get content pane and set its layout
27       Container container = getContentPane();
28       container.setLayout( layout );
29
30       // instantiate button objects
31       buttons = new JButton[ names.length ];
32
33       for ( int count = 0; count < names.length; count++ ) {
34          buttons[ count ] = new JButton( names[ count ] );
35          buttons[ count ].addActionListener( this );
36       }
37
38       // place buttons in BorderLayout; order not important
39       container.add( buttons[ 0 ], BorderLayout.NORTH );
40       container.add( buttons[ 1 ], BorderLayout.SOUTH );
41       container.add( buttons[ 2 ], BorderLayout.EAST );
42       container.add( buttons[ 3 ], BorderLayout.WEST );
43       container.add( buttons[ 4 ], BorderLayout.CENTER );
44
45       setSize( 300, 200 );
46       setVisible( true );
47    }
48
49    // handle button events
50    public void actionPerformed( ActionEvent event )
51    {
52       for ( int count = 0; count < buttons.length; count++ )
53
54          if ( event.getSource() == buttons[ count ] )
55             buttons[ count ].setVisible( false );
56          else
57             buttons[ count ].setVisible( true );
58
59       // re-layout the content pane
60       layout.layoutContainer( getContentPane() );
61    }
62
63    // execute application
64    public static void main( String args[] )
65    {
66       BorderLayoutDemo application = new BorderLayoutDemo();
```

Fig. 12.25 Demonstrating components in **`BorderLayout`** (part 2 of 3).

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```
67
68          application.setDefaultCloseOperation(
69             JFrame.EXIT_ON_CLOSE );
70       }
71
72    }  // end class BorderLayoutDemo
```

Fig. 12.25 Demonstrating components in **`BorderLayout`** (part 3 of 3).

Line 24 in the constructor defines a **`BorderLayout`**. The arguments specify the number of pixels between components that are arranged horizontally (*horizontal gap space*) and the number of pixels between components that are arranged vertically (*vertical gap space*), respectively. The default **`BorderLayout`** constructor supplies 0 pixels of gap space horizontally and vertically. Line 28 uses method **`setLayout`** to set the content pane's layout to **`layout`**.

Adding **`Component`**s to a **`BorderLayout`** requires a different add method from class **`Container`**, which takes two arguments—the **`Component`** to add and the region in which the **`Component`** will be placed. For example, line 39 specifies that the **`buttons[ 0 ]`** should appear in the **`NORTH`** position. The components can be added in any order, but only one component can be added to each region.

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Look-and-Feel Observation 12.11

If no region is specified when adding a ***Component*** *to a* ***BorderLayout****, it is assumed that the* ***Component*** *should be added to region* ***BorderLayout.CENTER****.*

Common Programming Error 12.6

Adding more than one component to a particular region in a ***BorderLayout*** *results in only the last component added being displayed. There is no error message to indicate this problem.*

When the user clicks on a particular **JButton** in the layout, method **actionPerformed** (lines 50–61) executes. The **for** loop at lines 52–57 uses an **if/else** structure to hide the particular **JButton** that generated the event. Method ***setVisible*** (inherited into **JButton** from class **Component**) is called with a **false** argument to hide the **JButton**. If the current **JButton** in the array is not the one that generated the event, method **setVisible** is called with a **true** argument to ensure that the **JButton** is displayed on the screen. Line 60 uses **LayoutManager** method **layoutContainer** to recalculate the layout of the content pane. Notice in the screen captures of Fig. 12.25 that certain regions in the **BorderLayout** change shape as **JButton**s are hidden and displayed in other regions. Try resizing the application window to see how the various regions resize based on the width and height of the window.

12.14.3 GridLayout

The ***GridLayout*** layout manager divides the container into a grid so that components can be placed in rows and columns. Class **GridLayout** inherits directly from class **Object** and implements interface **LayoutManager**. Every **Component** in a **GridLayout** has the same width and height. Components are added to a **GridLayout** starting at the top-left cell of the grid and proceeding left-to-right until the row is full. Then the process continues left-to-right on the next row of the grid, etc. Figure 12.26 demonstrates the **GridLayout** layout manager using six **JButton**s.

```
1  // Fig. 12.26: GridLayoutDemo.java
2  // Demonstrating GridLayout.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class GridLayoutDemo extends JFrame
12    implements ActionListener {
13
14    private JButton buttons[];
15    private String names[] =
16       { "one", "two", "three", "four", "five", "six" };
17    private boolean toggle = true;
```

Fig. 12.26 Program that demonstrates components in **GridLayout**.

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```
18    private Container container;
19    private GridLayout grid1, grid2;
20
21    // set up GUI
22    public GridLayoutDemo()
23    {
24       super( "GridLayout Demo" );
25
26       // set up layouts
27       grid1 = new GridLayout( 2, 3, 5, 5 );
28       grid2 = new GridLayout( 3, 2 );
29
30       // get content pane and set its layout
31       container = getContentPane();
32       container.setLayout( grid1 );
33
34       // create and add buttons
35       buttons = new JButton[ names.length ];
36
37       for ( int count = 0; count < names.length; count++ ) {
38          buttons[ count ] = new JButton( names[ count ] );
39          buttons[ count ].addActionListener( this );
40          container.add( buttons[ count ] );
41       }
42
43       setSize( 300, 150 );
44       setVisible( true );
45    }
46
47    // handle button events by toggling between layouts
48    public void actionPerformed( ActionEvent event )
49    {
50       if ( toggle )
51          container.setLayout( grid2 );
52       else
53          container.setLayout( grid1 );
54
55       toggle = !toggle;   // set toggle to opposite value
56       container.validate();
57    }
58
59    // execute application
60    public static void main( String args[] )
61    {
62       GridLayoutDemo application = new GridLayoutDemo();
63
64       application.setDefaultCloseOperation(
65          JFrame.EXIT_ON_CLOSE );
66    }
67
68 }  // end class GridLayoutDemo
```

Fig. 12.26 Program that demonstrates components in **`GridLayout`**.

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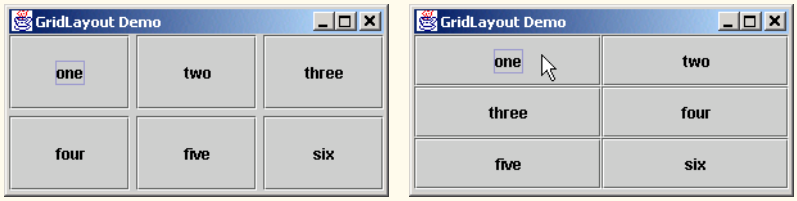

Fig. 12.26 Program that demonstrates components in **GridLayout**.

Lines 27–28 in the constructor define two **GridLayout** objects. The **GridLayout** constructor used at line 27 specifies a **GridLayout** with **2** rows, **3** columns, **5** pixels of horizontal-gap space between **Component**s in the grid and **5** pixels of vertical-gap space between **Component**s in the grid. The **GridLayout** constructor used at line 28 specifies a **GridLayout** with **3** rows, **2** columns and no gap space.

The **JButton** objects in this example initially are arranged using **grid1** (set for the content pane at line 32 with method **setLayout**). The first component is added to the first column of the first row. The next component is added to the second column of the first row, and so on. When a **JButton** is pressed, method **actionPerformed** (lines 48–57) is called. Every call to **actionPerformed** toggles the layout between **grid2** and **grid1**.

Line 56 illustrates another way to relayout a container for which the layout has changed. **Container** method ***validate*** recomputes the container's layout based on the current layout manager for the **Container** and the current set of displayed GUI components.

12.15 Panels

Complex GUIs (like Fig. 12.1) require that each component be placed in an exact location. They often consist of multiple *panels* with each panel's components arranged in a specific layout. Panels are created with class ***JPanel***—a subclass of **JComponent**. Class **JComponent** inherits from class **java.awt.Container**, so every **JPanel** is a **Container**. Thus **JPanel**s may have components, including other panels, added to them.

The program of Fig. 12.27 demonstrates how a **JPanel** can be used to create a more complex layout for **Component**s.

```
1  // Fig. 12.27: PanelDemo.java
2  // Using a JPanel to help lay out components.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class PanelDemo extends JFrame {
12    private JPanel buttonPanel;
```

Fig. 12.27 A **JPanel** with five **JButton**s in a **GridLayout** attached to the **SOUTH** region of a **BorderLayout** (part 1 of 2).

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```
13     private JButton buttons[];
14
15     // set up GUI
16     public PanelDemo()
17     {
18        super( "Panel Demo" );
19
20        // get content pane
21        Container container = getContentPane();
22
23        // create buttons array
24        buttons = new JButton[ 5 ];
25
26        // set up panel and set its layout
27        buttonPanel = new JPanel();
28        buttonPanel.setLayout(
29           new GridLayout( 1, buttons.length ) );
30
31        // create and add buttons
32        for ( int count = 0; count < buttons.length; count++ ) {
33           buttons[ count ] =
34              new JButton( "Button " + ( count + 1 ) );
35           buttonPanel.add( buttons[ count ] );
36        }
37
38        container.add( buttonPanel, BorderLayout.SOUTH );
39
40        setSize( 425, 150 );
41        setVisible( true );
42     }
43
44     // execute application
45     public static void main( String args[] )
46     {
47        PanelDemo application = new PanelDemo();
48
49        application.setDefaultCloseOperation(
50           JFrame.EXIT_ON_CLOSE );
51     }
52
53  }  // end class PanelDemo
```

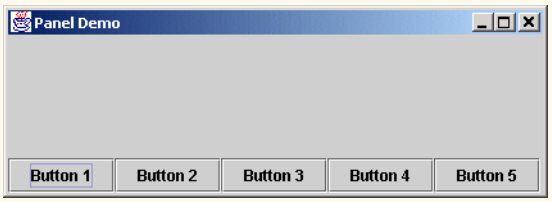

Fig. 12.27 A **JPanel** with five **JButton**s in a **GridLayout** attached to the **SOUTH** region of a **BorderLayout** (part 2 of 2).

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After **JPanel buttonPanel** is created at line 27, lines 28–29 set **buttonPanel**'s layout to a **GridLayout** of one row and five columns (there are five **JButton**s in array **buttons**). The five **JButton**s in array **buttons** are added to the **JPanel** in the loop with line 35. Notice that the buttons are added directly to the **JPanel**—class **JPanel** does not have a content pane like an applet or a **JFrame**. Line 38 uses the content pane's default **BorderLayout** to add **buttonPanel** to the **SOUTH** region. Note that the **SOUTH** region is as tall as the buttons on **buttonPanel**. A **JPanel** is sized to the components it contains. As more components are added, the **JPanel** grows (according to the restrictions of its layout manager) to accommodate the components. Resize the window to see how the layout manager affects the size of the **JButton**s.

12.16 (Optional Case Study) Thinking About Objects: Use Cases

The previous eight "Thinking About Objects" sections have concentrated on the elevator-simulation model. We have identified and honed the structure and behavior of our system. In this section, we model the interaction between the user and our elevator simulation through the UML use-case diagram, which describes the sets of scenarios that occur between the user and the system.

Use-Case Diagrams

When developers begin a project, they rarely start with as detailed a problem statement as the one we provided in Section 2.9. This document and others are the result of the *object-oriented analysis* (OOA) phase. In this phase you meet with the people who want you to build a system and with the people who will eventually use that system. You use the information gained in these meetings to compile a list of *system requirements*. These requirements guide you and your fellow developers as you design the system. In our case study, the problem statement described the requirements of our elevator simulation in sufficient detail that you did not need to go through an analysis phase. The analysis phase is enormously important—you should consult the references we provide in Section 2.9 to learn more about object-oriented analysis.

The UML provides the *use-case diagram* to facilitate requirements gathering. This diagram models the interactions between the system's external clients and the *use cases* of the system. Each use case represents a different capability that the system provides to clients. For example, automated teller machines typically have several use cases, including "Deposit Money," "Withdraw Money" and "Transfer Funds."

In larger systems, use-case diagrams are indispensable tools that help system designers remain focused on satisfying the users' needs. The goal of the use-case diagram is to show the kinds of interactions users have with a system without providing the details of those interactions: those details are, of course, provided in other UML diagrams.

Figure 12.28 shows the use-case diagram for our elevator simulation. The stick figure represents an *actor*, which, in turn, represents a set of roles that an *external entity*—such as a person or another system—can play. Consider again our automated teller machine example. The actor is a **BankCustomer** who can deposit, withdraw and transfer funds from the ATM. In this sense, **BankCustomer** is more like a class rather than an object—it is not an actual person, but rather describes the roles that a real person—when playing the part of a **BankCustomer**—can perform while interacting with the ATM (deposit, with-

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draw and transfer funds). A person is an external entity that can play the part of a **BankCustomer**. In the same manner as an object is an instance of a class, a person playing the part of a **BankCustomer** performing one of its roles (such as making a deposit) is an *instance of actor* **BankCustomer**. For example, when a person named Mary plays the part of a **BankCustomer** making a deposit, Mary—in the role of the depositor—becomes an instance of actor **BankCustomer**. Later in that day, another person named Jon can be another instance of actor **BankCustomer**. In the course of a day, several hundred people might use the ATM machine—some are "depositors", some are "withdrawers" and some are "transferrers," but all of these people are instances of actor **BankCustomer**.

The problem statement in our elevator simulation supplies the actors—"The user requires the ability to create a person in the simulation and situate that person on a given floor." Therefore, the actor of our system is the user who controls the simulation (i.e., the user who clicks the buttons to create new **Person**s in the simulation). An external entity—a real person—plays the part of the user to control the simulation. In our system, the use case is "Create Person," which encompasses creating a **Person** object, then placing that **Person** on either the first or second **Floor**. Figure 12.28 models one actor called "User." The actor's *name* appears underneath the actor.

The *system box* (i.e., the enclosing rectangle in the figure) contains the use cases for the system. Notice that the box is labeled "Elevator Simulation." This title shows that this use-case model focuses on the one use case that our simulation provides to users (i.e., "Create Person"). The UML models each use case as an oval. The system box for a system with multiple use cases would have one oval per use case.

There is a reasonable alternate view of the use case of our elevator simulation. The problem statement from Section 2.9 mentioned that the company requested the elevator simulation to "determine whether the elevator will meet the company's needs." We are designing a simulation of a real-world scenario—the **Person** object in the simulation represents an actual human being using an actual elevator. Thus, we may view the user of the elevator simulation as the user of the elevator. Therefore, specifying a use case from the **Person** object's perspective helps model how a real person uses a real elevator system. We offer the use case of Fig. 12.29, titled "Relocate Person." This use case describes the **Person** moving (relocating) to the other **Floor**. (The **Person** travels to the second **Floor** if starting on the first **Floor** and to the first **Floor** if starting on the second **Floor**.) This use case encompasses all actions that the **Person** performs along his or her journey, such as walking across a **Floor** to the **Elevator**, pressing **Button**s and riding the **Elevator** to the other **Floor**.

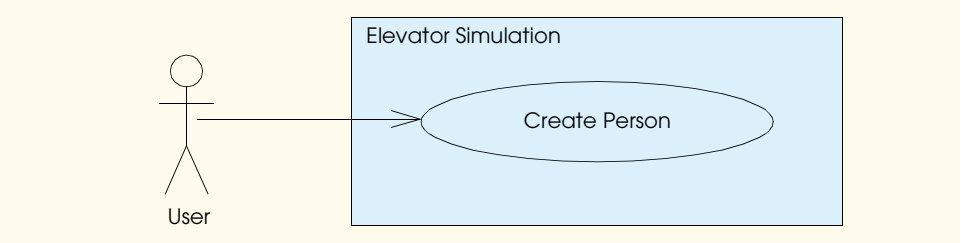

Fig. 12.28 Use-case diagram for elevator simulation from user's perspective.

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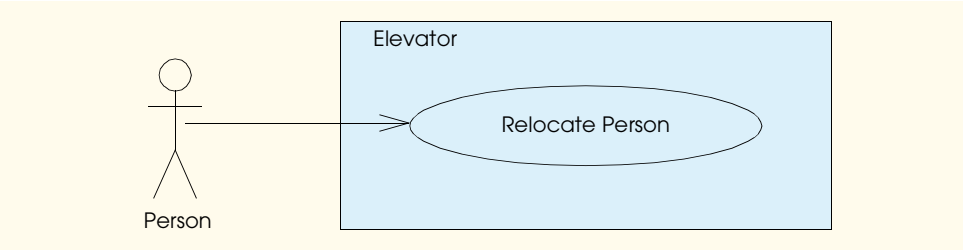

Fig. 12.29 Use-case diagram from the perspective of a **Person**.

We must ensure that our use cases do not model interactions that are too specific between the external client and the system. For example, we do not subdivide each use case into two separate use cases—such as "Create Person on first Floor" and "Create Person on second Floor," or "Relocate Person to first Floor" and "Relocate Person to second Floor"—because the functionality of such use cases is repetitive (i.e., these seemingly alternative use cases are really the same). Improper and repetitive subdivision of use cases can create problems during implementation. For example, if the designer of an automated teller machine separated its "Withdraw Money" use case into "Withdraw Specific Amounts" use cases (e.g., "Withdraw $1.00," "Withdraw $2.00," etc.), there could exist an enormous number of use cases for the system. This would make the implementation tedious. (Our elevator system contains only two floors—separating the use case into two would not cause that much extra work; if our system contained 100 floors, however, creating 100 use cases would be unwieldy.)

Constructing the Graphical User Interface

Our simulation implements both the "Create Person" and "Relocate Person" use cases. We have studied the "Relocate Person" use case through the activity diagram of the **Person** in Fig. 5.29—we implement this use case and the activity diagram in Appendix H when we create class **Person**. We implement the "Create Person" use case through a graphical user interface (GUI). We implement our GUI in class **ElevatorController** (Fig. 12.30, line 17), which is a **JPanel** subclass containing two **JButton** objects—**firstControllerButton** (line 21) and **secondControllerButton** (line 22). Each **JButton** corresponds to a **Floor** on which to place a **Person**.[1] Lines 33–38 instantiate these **JButton**s and add them to the **ElevatorController**.

We discuss in Section 13.17 how class **ElevatorModel** ties together all objects composing our elevator simulation model. Line 25 of class **ElevatorController** declares a reference to the **ElevatorModel**, because the **ElevatorController** allows the user to interact with the model. Lines 42–56 and 60–74 declare two anonymous **ActionListener** objects and register them with **firstFloorControllerButton** and **secondFloorControllerButton**, respectively, for **ActionEvent**s. When the user presses either **JButton**, lines 49–50 and 67–68 of methods **actionPer-**

1. This approach is feasible with only two **Floor**s. If the building had 100 **Floor**s, we might have opted for the user to specify the desired **Floor** in a **JTextField** and press a **JButton** to process the request.

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formed call the **ElevatorModel**'s method **placePersonOnFloor**, which instantiates a **Person** object in the **ElevatorModel** on the specified **Floor**. Method **placePersonOnFloor** takes as an argument a **String** defined in interface **ElevatorConstants** (Fig. 12.31). This interface—used by such classes as **ElevatorController**, **ElevatorModel**, **Elevator**, **Floor** and **ElevatorView**—provides constants that specify the names of **Location**s in our simulation.

```
1  // ElevatorController.java
2  // Controller for Elevator Simulation
3  package com.deitel.jhtp4.elevator.controller;
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 // Deitel packages
13 import com.deitel.jhtp4.elevator.model.*;
14 import com.deitel.jhtp4.elevator.event.*;
15 import com.deitel.jhtp4.elevator.ElevatorConstants;
16
17 public class ElevatorController extends JPanel
18    implements ElevatorConstants {
19
20    // controller contains two JButtons
21    private JButton firstControllerButton;
22    private JButton secondControllerButton;
23
24    // reference to model
25    private ElevatorModel elevatorModel;
26
27    public ElevatorController( ElevatorModel model )
28    {
29       elevatorModel = model;
30       setBackground( Color.white );
31
32       // add first button to controller
33       firstControllerButton = new JButton( "First Floor" );
34       add( firstControllerButton );
35
36       // add second button to controller
37       secondControllerButton = new JButton( "Second Floor" );
38       add( secondControllerButton );
39
40       // anonymous inner class registers to receive ActionEvents
41       // from first Controller JButton
42       firstControllerButton.addActionListener(
43          new ActionListener() {
44
```

Fig. 12.30 Class **ElevatorController** processes user input (part 1 of 3).

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```
45             // invoked when a JButton has been pressed
46             public void actionPerformed( ActionEvent event )
47             {
48                // place Person on first Floor
49                elevatorModel.placePersonOnFloor(
50                   FIRST_FLOOR_NAME );
51
52                // disable user input
53                firstControllerButton.setEnabled( false );
54             }
55          } // end anonymous inner class
56       );
57
58       // anonymous inner class registers to receive ActionEvents
59       // from second Controller JButton
60       secondControllerButton.addActionListener(
61          new ActionListener() {
62
63             // invoked when a JButton has been pressed
64             public void actionPerformed( ActionEvent event )
65             {
66                // place Person on second Floor
67                elevatorModel.placePersonOnFloor(
68                   SECOND_FLOOR_NAME );
69
70                // disable user input
71                secondControllerButton.setEnabled( false );
72             }
73          } // end anonymous inner class
74       );
75
76       // anonymous inner class enables user input on Floor if
77       // Person enters Elevator on that Floor
78       elevatorModel.addPersonMoveListener(
79          new PersonMoveListener() {
80
81             // invoked when Person has entered Elevator
82             public void personEntered(
83                PersonMoveEvent event )
84             {
85                // get Floor of departure
86                String location =
87                   event.getLocation().getLocationName();
88
89                // enable first JButton if first Floor departure
90                if ( location.equals( FIRST_FLOOR_NAME ) )
91                   firstControllerButton.setEnabled( true );
92
93                // enable second JButton if second Floor
94                else
95                   secondControllerButton.setEnabled( true );
96
97             } // end method personEntered
```

Fig. 12.30 Class **ElevatorController** processes user input (part 2 of 3).

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```
98
99             // other methods implementing PersonMoveListener
100            public void personCreated(
101               PersonMoveEvent event ) {}
102
103            public void personArrived(
104               PersonMoveEvent event ) {}
105
106            public void personExited(
107               PersonMoveEvent event ) {}
108
109            public void personDeparted(
110               PersonMoveEvent event ) {}
111
112            public void personPressedButton(
113               PersonMoveEvent event ) {}
114
115         } // end anonymous inner class
116      );
117   } // end ElevatorController constructor
118 }
```

Fig. 12.30 Class **ElevatorController** processes user input (part 3 of 3).

Lines 53 and 71 of methods **actionPerformed** disable the respective **JButton**s to prevent the user from creating more than one **Person** per **Floor**. Lines 78–116 of class **ElevatorController** declare an anonymous **PersonMoveListener** that registers with the **ElevatorModel** to reenable the **JButton**s. Method **personEntered** (lines 82–97) of the **PersonMoveListener** reenables the **JButton** associated with the **Floor** that the **Elevator** services—after the **Person** has entered the **Elevator**, the user may place another **Person** on the **Floor**.

We mentioned in Section 9.23 that classes **Elevator** and **Floor** inherited attribute **capacity** from superclass **Location**—in Appendix H, we were going to use this attribute to prevent more than one **Person** from occupying a **Location**. However, the **PersonMoveListener**'s method **personEntered** in class **ElevatorController** prevents the user from creating more than one **Person** per **Floor**. Therefore, we have negated the need for attribute **capacity** in class **Location**. Figure 12.32 is the modified class diagram of Fig. 9.18 removing this attribute.

```
1  // ElevatorConstants.java
2  // Constants used between ElevatorModel and ElevatorView
3  package com.deitel.jhtp4.elevator;
4
5  public interface ElevatorConstants {
6
7     public static final String FIRST_FLOOR_NAME = "firstFloor";
8     public static final String SECOND_FLOOR_NAME = "secondFloor";
9     public static final String ELEVATOR_NAME = "elevator";
10 }
```

Fig. 12.31 Interface **ElevatorConstants** provides **Location** name constants.

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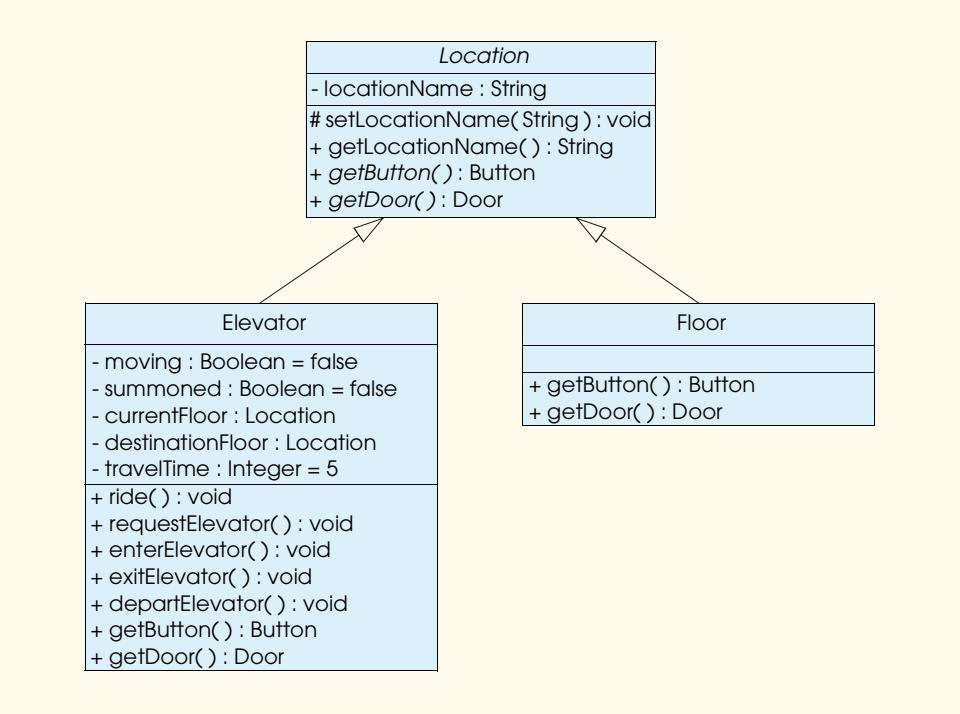

Fig. 12.32 Modified class diagram showing generalization of superclass **`Location`** and subclasses **`Elevator`** and **`Floor`**.

In this section we mentioned that the goal of object-oriented ananlysis is to produce a system-requirements document. We introduced the UML use-case diagram that facilitates gathering system requirements, and we examined the two use cases in our elevator simulation. We implemented our simulator's Graphical User Interface in Java.

This section concludes the discussion on the interaction between the user and the simulation model. In "Thinking About Objects" Section 13.17, we integrate class **`ElevatorController`** with the rest of the simulation. We also introduce the UML Component diagram, which models the **`.class`**, **`.java`**, image and sound files that comprise our system.

SUMMARY

- A graphical user interface (GUI) presents a pictorial interface to a program. A GUI (pronounced "GOO-EE") gives a program a distinctive "look" and "feel."
- By providing different applications with a consistent set of intuitive user interface components, GUIs allow the user to spend more time using the program in a productive manner.
- GUIs are built from GUI components (sometimes called controls or widgets). A GUI component is a visual object with which the user interacts via the mouse or the keyboard.
- Swing GUI components are defined in package **`javax.swing`**. Swing components are written, manipulated and displayed completely in Java.

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- The original GUI components from the Abstract Windowing Toolkit package **`java.awt`** are tied directly to the local platform's graphical user interface capabilities.
- Swing components are lightweight components. AWT components are tied to the local platform and are called heavyweight components—they must rely on the local platform's windowing system to determine their functionality and their look and feel.
- Several Swing GUI components are heavyweight GUI components: in particular, subclasses of **`java.awt.Window`** (such as **`JFrame`**) that display windows on the screen. Heavyweight Swing GUI components are less flexible than lightweight components.
- Much of each Swing GUI component's functionality is inherited from classes **`Component`**, **`Container`** and **`JComponent`** (the superclass to most Swing components).
- A Container is an area where components can be placed.
- **`JLabel`**s provide text instructions or information on a GUI.
- **`JComponent`** method **`setToolTipText`** specifies the tool tip that is displayed automatically when the user positions the mouse cursor over a **`JComponent`** in the GUI.
- Many Swing components can display images by specifying an **`Icon`** as an argument to their constructor or by using a method **`setIcon`**.
- Class **`ImageIcon`** (package **`javax.swing`**) supports several image formats, including Portable Network Graphics (PNG), Graphics Interchange Format (GIF) and Joint Photographic Experts Group (JPEG).
- Interface **`SwingConstants`** (package **`javax.swing`**) defines a set of common integer constants (such as **`SwingConstants.LEFT`**) that are used with many Swing components.
- By default, the text of a **`JComponent`** appears to the right of the image when the **`JComponent`** contains both text and an image.
- The horizontal and vertical alignments of a **`JLabel`** can be set with methods **`setHorizontalAlignment`** and **`setVerticalAlignment`**. Method **`setText`** sets the text displayed on the label. Method **`getText`** retrieves the current text displayed on a label. Methods **`setHorizontalTextPosition`** and **`setVerticalTextPosition`** specify the text position in a label.
- **`JComponent`** method **`setIcon`** sets the **`Icon`** displayed on a **`JComponent`**. Method **`getIcon`** retrieves the current **`Icon`** displayed on a **`JComponent`**.
- GUIs generate events when the user interacts with the GUI. Information about a GUI event is stored in an object of a class that extends **`AWTEvent`**.
- To process an event, the programmer must register an event listener and implement one or more event handlers.
- The use of event listeners in event handling is known as the delegation event model—the processing of an event is delegated to a particular object in the program.
- When an event occurs, the GUI component with which the user interacted notifies its registered listeners by calling each listener's appropriate event handling method.
- **`JTextFields`** and **`JPasswordFields`** are single-line areas in which text can be entered by the user from the keyboard or text can simply be displayed. A **`JPasswordField`** shows that a character was typed as the user enters characters, but automatically hides the characters.
- When the user types data into a **`JTextField`** or **`JPasswordField`** and presses the Enter key, an **`ActionEvent`** occurs.
- **`JTextComponent`** method **`setEditable`** determines whether the user can modify the text in a **`JTextComponent`**.
- **`JPasswordField`** method **`getPassword`** returns the password as an array of type **`char`**.

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- Every **JComponent** contains an object of class **EventListenerList** (package **javax.swing.event**) called **listenerList** in which all registered listeners are stored.
- Every **JComponent** supports several different event types, including mouse events, key events and others. When an event occurs, the event is dispatched only to the event listeners of the appropriate type. Each event type has a corresponding event-listener interface.
- When an event is generated by a user interaction with a component, the component is handed a unique event ID specifying the event type. The GUI component uses the event ID to decide the type of listener to which the event should be dispatched and the event handler method to call.
- A **JButton** generates an **ActionEvent** when the user clicks the button with the mouse.
- An **AbstractButton** can have a rollover **Icon** that is displayed when the mouse is positioned over the button. The icon changes as the mouse moves in and out of the button's area on the screen. **AbstractButton** method **setRolloverIcon** specifies the image displayed on a button when the user positions the mouse over the button.
- The Swing GUI components contain three state button types—**JToggleButton**, **JCheckBox** and **JRadioButton**—that have on/off or true/false values. Classes **JCheckBox** and **JRadioButton** are subclasses of **JToggleButton**.
- When the user clicks a **JCheckBox**, an **ItemEvent** is generated that can be handled by an **ItemListener**. **ItemListener**s must define method **itemStateChanged**. **ItemEvent** method **getStateChange** determines the state of a **JToggleButton**.
- **JRadioButtons** are similar to **JCheckBox**es in that they have two states—selected and not selected (also called deselected). **JRadioButtons** normally appear as a group in which only one radio button can be selected at a time.
- The logical relationship between radio buttons is maintained by a **ButtonGroup** object.
- The **JRadioButton** constructor supplies the label that appears to the right of the **JRadioButton** by default and the initial state of the **JRadioButton**. A **true** second argument indicates that the **JRadioButton** should appear selected when it is displayed.
- **JRadioButton**s generate **ItemEvent**s when they are clicked.
- **ButtonGroup** method **add** associates a **JRadioButton** with a **ButtonGroup**. If more than one selected **JRadioButton** object is added to the group, the last selected **JRadioButton** added will be selected when the GUI is displayed.
- A **JComboBox** (sometimes called a drop-down list) provides a list of items from which the user can make a selection. **JComboBox**es generate **ItemEvent**s. A numeric index keeps track of the ordering of items in a JComboBox. The first item is added at index 0, the next item is added at index 1 and so forth. The first item added to a JComboBox appears as the currently selected item when the JComboBox is displayed. **JComboBox** method **getSelectedIndex** returns the index number of the selected item.
- A **JList** displays a series of items from which the user may select one or more items. Class **JList** supports single- and multiple-selection lists. When an item is clicked in a **JList**, a **ListSelectionEvent** occurs.
- **JList** method **setVisibleRowCount** determines the number of items that are visible in the list. Method **setSelectionMode** specifies the selection mode for the list.
- Class **JList** does *not* automatically provide a scrollbar if there are more items in the list than the number of visible rows. A **JScrollPane** object is used to provide the automatic scrolling capability for a **JList**.
- A **SINGLE_INTERVAL_SELECTION** list allows selection of a contiguous range of items by clicking the first item, then holding the Shift key while clicking the last item to select in the range.

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- A **MULTIPLE_INTERVAL_SELECTION** list allows continuous range selection as described for a **SINGLE_INTERVAL_SELECTION** list and allows miscellaneous items to be selected by holding the Ctrl key while clicking each item to select.
- **JList** method **setFixedCellHeight** specifies the height in pixels of each item in a **JList**. Method **setFixedCellWidth** sets the width in pixels of a **JList**.
- Normally, an event generated by another GUI component (known as an external event) specifies when the multiple selections in a **JList** should be processed.
- **JList** method **setListData** sets the items displayed in a **JList**. Method **getSelectedValues** returns the selected items as an array of **Object**s.
- Mouse events can be trapped for any GUI component that derives from **java.awt.Component** using **MouseListener**s and **MouseMotionListener**s.
- Each mouse event handling method takes as its argument a **MouseEvent** object containing information about the mouse event and the location where the event occurred.
- Methods **addMouseListener** and **addMouseMotionListener** are **Component** methods used to register mouse event listeners for an object of any class that extends **Component**.
- Many of the event-listener interfaces provide multiple methods. For each, there is a corresponding event-listener adapter class that provides a default implementation of every method in the interface. The programmer can extend the adapter class to inherit the default implementation of every method and simply override the method or methods needed for event handling in the program.
- **MouseEvent** method **getClickCount** returns the number of mouse clicks.
- **InputEvent** methods **isMetaDown** and **isAltDown** are used to determine which mouse button the user clicked.
- **KeyListener**s handle key events that are generated when keys on the keyboard are pressed and released. A **KeyListener** must provide definitions for methods **keyPressed**, **keyReleased** and **keyTyped**, each of which receives a **KeyEvent** as its argument.
- Method **keyPressed** is called in response to pressing any key. Method **keyTyped** is called in response to pressing any key that is not an action key (i.e., an arrow key, *Home*, *End*, *Page Up*, *Page Down*, a function key, *Num Lock*, *Print Screen*, *Scroll Lock*, *Caps Lock* and *Pause*). Method **keyReleased** is called when the key is released after any **keyPressed** or **keyTyped** event.
- **KeyEvent** method **getKeyCode** gets the virtual key code of the key that was pressed. Class **KeyEvent** maintains a set of virtual key code constants that represent every key on the keyboard.
- **KeyEvent** method **getKeyText** returns a **String** containing the name of the key that corresponds to its virtual key code argument. Method **getKeyChar** gets the Unicode value of the character typed. Method **isActionKey** determines if the key in the event was an action key.
- **InputEvent** method **getModifiers** determines if any modifier keys (such as Shift, Alt and Ctrl) were pressed when the key event occurred. **KeyEvent** method **getKeyModifiersText** produces a string containing the names of the pressed modifier keys.
- Layout managers arrange GUI components on a container for presentation purposes.
- **FlowLayout** lays out components from left to right in the order in which they are added to the container. When the edge of the container is reached, components are continued on the next line.
- **FlowLayout** method **setAlignment** changes the alignment for the **FlowLayout** to **FlowLayout.LEFT**, **FlowLayout.CENTER** or **FlowLayout.RIGHT**.
- The **BorderLayout** layout manager arranges components into five regions: North, South, East, West and Center. One component can be added to each region.

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- **`LayoutManager`** method **`layoutContainer`** recalculates the layout of its **`Container`** argument.
- The **`GridLayout`** layout manager divides the container into a grid of rows and columns. Components are added to a **`GridLayout`** starting at the top-left cell and proceeding from left to right until the row is full. Then the process continues from left to right on the next row of the grid, and so on.
- **`Container`** method **`validate`** recomputes the container's layout based on the current layout manager for the **`Container`** and the current set of displayed GUI components.
- Panels are created with class **`JPanel`**, which inherits from class JComponent. JPanels may have components, including other panels, added to them.

TERMINOLOGY

`.gif` file name extension
`.jpg` file name extension
"listen" for an event
Abstract Windowing Toolkit
`AbstractButton` class
`ActionEvent` class
`ActionListener` interface
`actionPerformed` method
adapter class
`add` method of **`ButtonGroup`**
`add` method of class **`Container`**
`addItemListener` method
`addKeyListener` method
`addListSelectionListener` method
`addMouseListener` method
`addMouseMotionListener` method
assistive technologies
`BorderLayout` class
`BorderLayout.CENTER`
`BorderLayout.EAST`
`BorderLayout.NORTH`
`BorderLayout.SOUTH`
`BorderLayout.WEST`
button
button label
`ButtonGroup` class
centered
check box
check box label
command button
`Component` class
`ComponentAdapter` class
`ComponentListener` interface
`Container` class
`ContainerAdapter` class
`ContainerListener` interface
control
delegation event model
dispatch an event
dragging
drop-down list
event
event driven
event handler
event ID
event listener
event-listener interface
`EventListenerList` class
`EventObject` class
`FlowLayout` class
`FlowLayout.CENTER`
`FlowLayout.LEFT`
`FlowLayout.RIGHT`
focus
`FocusAdapter` class
`FocusListener` interface
`Font.BOLD`
`Font.ITALIC`
`Font.PLAIN`
`getActionCommand` method
`getClickCount` method
`getIcon` method
`getKeyChar` method of **`KeyEvent`**
`getKeyCode` method of **`KeyEvent`**
`getKeyModifiersText` method
`getKeyText` method of **`KeyEvent`**
`getModifiers` method of **`InputEvent`**
`getPassword` method of **`JPasswordField`**
`getSelectedIndex` method of **`JComboBox`**
`getSelectedIndex` method of **`JList`**
`getSelectedValues` method of **`JList`**
`getSource` method of **`ActionEvent`**
`getStateChange` method of **`ItemEvent`**
`getText` method of **`JLabel`**
`getX` method of **`MouseEvent`**
`getY` method of **`MouseEvent`**

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Graphics Interchange Format (GIF)
GridLayout class
GUI component
heavyweight component
horizontal gap space
Icon interface
ImageIcon class
InputEvent class
isActionKey method of **KeyEvent**
isAltDown method of **InputEvent**
isMetaDown method of **InputEvent**
ItemEvent class
ItemEvent.DESELECTED
ItemEvent.SELECTED
ItemListener interface
itemStateChanged method
java.awt package
java.awt.event package
javax.swing package
javax.swing.event package
JButton class
JCheckBox class
JComboBox class
JComponent class
JLabel class
JList class
Joint Photographic Experts Group (JPEG)
JPanel class
JPasswordField class
JRadioButton class
JScrollPane class
JTextComponent class
JTextField class
JToggleButton class
KeyAdapter class
KeyEvent class
KeyListener interface
keyPressed method of **KeyListener**
keyReleased method of **KeyListener**
keyTyped method of **KeyListener**
label
layout manager
layoutContainer method
LayoutManger interface
left aligned
left justified
lightweight component
ListSelectionEvent class
ListSelectionListener interface
ListSelectionModel interface
look and feel
menu
menu bar
MouseAdapter class
mouseClicked method
mouseDragged method
mouseEntered method
MouseEvent class
mouseExited method
MouseListener interface
MouseMotionAdapter class
MouseMotionListener interface
mouseMoved method
mousePressed method
mouseReleased method
multiple-selection list
password
pluggable look and feel
radio button
read-only text
register an event listener
right-aligned
rollover icon
scroll arrow
scroll box
scrollbar
selection mode
setAlignment method
setBackground method
setEditable method
setFixedCellHeight method
setFixedCellWidth method
setHorizontalAlignment method
setHorizontalTextPosition method
setIcon method
setLayout method of class **Container**
setListData method of **JList**
setMaximumRowCount method
setRolloverIcon method
setSelectionMode method
setToolTipText method
setVerticalAlignment method
setVerticalTextPosition method
setVisible method
setVisibleRowCount method
shortcut key (mnemonics)
single-selection list
SwingConstants interface
tool tips
toolbar

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user interface localization
validate method
valueChanged method
vertical gap space
widget (window gadget)
window
WindowAdapter class
windowClosing method
windowing system
WindowListener interface

SELF-REVIEW EXERCISES

12.1 Fill in the blanks in each of the following statements:

a) Method _____ is called when the mouse is moved and an event listener is registered to handle the event.
b) Text that cannot be modified by the user is called _____ text.
c) A _____ arranges GUI components on a **Container**.
d) The **add** method for attaching GUI components is a _____ class method.
e) GUI is an acronym for _____.
f) Method _____ is used to set the layout manager for a container.
g) A **mouseDragged** method call is preceded by a _____ method call and followed by a _____ method call.

12.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) **BorderLayout** is the default layout manager for a content pane.
b) When the mouse cursor is moved into the bounds of a GUI component, method **mouseOver** is called.
c) A **JPanel** cannot be added to another **JPanel**.
d) In a **BorderLayout**, two buttons added to the **NORTH** region will be placed side by side.
e) When one is using **BorderLayout**, a maximum of five components may be used.

12.3 Find the error(s) in each of the following and explain how to correct it (them).

a)
```
buttonName = JButton( "Caption" );
```
b)
```
JLabel aLabel, JLabel;      // create references
```
c)
```
txtField = new JTextField( 50, "Default Text" );
```
d)
```
Container container = getContentPane();
setLayout( new BorderLayout() );
button1 = new JButton( "North Star" );
button2 = new JButton( "South Pole" );
container.add( button1 );
container.add( button2 );
```

ANSWERS TO SELF-REVIEW EXERCISES

12.1 a) **mouseMoved**. b) uneditable (read-only). c) layout manager. d) **Container**. e) graphical user interface. f) **setLayout**. g) **mousePressed**, **mouseReleased**.

12.2 a) True.
b) False. Method **mouseEntered** is called.
c) False. A **JPanel** can be added to another **JPanel** because **JPanel** derives indirectly from **Component**. Therefore, a **JPanel** is a **Component**. Any **Component** can be added to a **Container**.
d) False. Only the last button added will be displayed. Remember that only one component can be added to each region in a **BorderLayout**.
e) True.

12.3 a) **new** is needed to instantiate the object.
b) JLabel is a class name and cannot be used as a variable name.

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c) The arguments passed to the constructor are reversed. The **`String`** must be passed first.
d) **`BorderLayout`** has been set and components are being added without specifying the region. Proper **`add`** statements might be

```
container.add( button1, BorderLayout.NORTH );
container.add( button2, BorderLayout.SOUTH );
```

EXERCISES

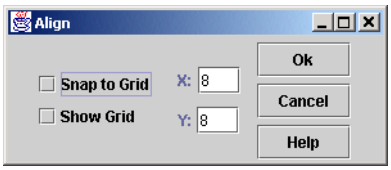
12.4 Fill in the blanks in each of the following statements:
a) The **`JTextField`** class inherits directly from _____.
b) The layout managers discussed in this chapter are _____, _____ and _____.
c) **`Container`** method _____ attaches a GUI component to a container.
d) Method _____ is called when a mouse button is released (without moving the mouse).
e) The _____ class is used to create a group of **`JRadioButton`**s.

12.5 State whether each of the following is *true* or *false*. If *false*, explain why.
a) Only one layout manager can be used per **`Container`**.
b) GUI components can be added to a **`Container`** in any order in a **`BorderLayout`**.
c) **`JRadioButton`**s provide a series of mutually exclusive options (only one can be **`true`** at a time).
d) **`Graphics`** method **`setFont`** is used to set the font for text fields.
e) A **`JList`** displays a scrollbar if there are more items in the list than can be displayed.
f) A **`Mouse`** object contains a method called **`mouseDragged`**.

12.6 State whether each of the following is *true* or *false*. If *false*, explain why.
a) A **`JApplet`** does not have a content pane.
b) A **`JPanel`** is a **`JComponent`**.
c) A **`JPanel`** is a **`Component`**.
d) A **`JLabel`** is a **`Container`**.
e) A **`JList`** is a **`JPanel`**.
f) An **`AbstractButton`** is a **`JButton`**.
g) A **`JTextField`** is an **`Object`**.
h) **`ButtonGroup`** inherits from JComponent.

12.7 Find any error(s) in each of the following and explain how to correct it (them).
a)
```
import javax.swing.*          // include swing package
```
b)
```
panelObject.GridLayout( 8, 8 ); // set GridLayout
```
c)
```
container.setLayout(
   new FlowLayout( FlowLayout.DEFAULT ) );
```
d)
```
container.add( eastButton, EAST );  // BorderLayout
```

12.8 Create the following GUI. You do not have to provide any functionality.



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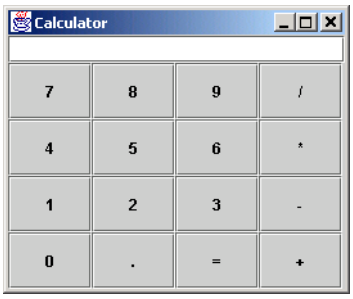
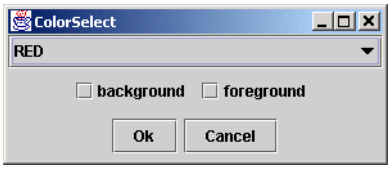
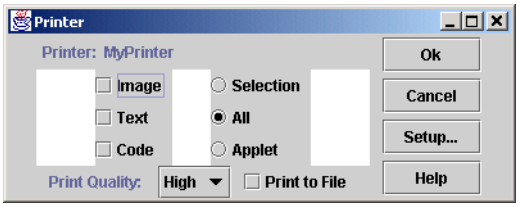
12.9 Create the following GUI. You do not have to provide any functionality.



12.10 Create the following GUI. You do not have to provide any functionality.



12.11 Create the following GUI. You do not have to provide any functionality.



12.12 Write a temperature conversion program that converts from Fahrenheit to Celsius. The Fahrenheit temperature should be entered from the keyboard (via a **`JTextField`**). A **`JLabel`** should be used to display the converted temperature. Use the following formula for the conversion:

$$Celsius = 5 / 9 \times (Fahrenheit - 32)$$

12.13 Enhance the temperature conversion program of Exercise 12.12 by adding the Kelvin temperature scale. The program should also allow the user to make conversions between any two scales. Use the following formula for the conversion between Kelvin and Celsius (in addition to the formula in Exercise 12.12):

$$Kelvin = Celsius + 273$$

12.14 Write an application that allows the user to draw a rectangle by dragging the mouse on the application window. The upper-left coordinate should be the location where the user presses the mouse button, and the lower-right coordinate should be the location where the user releases the mouse button. Also display the area of the rectangle in a **`JLabel`** in the **`SOUTH`** region of a **`BorderLayout`**. Use the following formula for the area:

$$area = width \times height$$

12.15 Modify the program of Exercise 12.14 to draw different shapes. The user should be allowed to choose from an oval, an arc, a line, a rectangle with rounded corners and a predefined polygon. Also display the mouse coordinates in the status bar.

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12.16 Write a program that will allow the user to draw a shape with the mouse. The shape to draw should be determined by a **KeyEvent** using the following keys: *c* draws a circle, *o* draws an oval, *r* draws a rectangle and *l* draws a line. The size and placement of the shape should be determined by the **mousePressed** and **mouseReleased** events. Display the name of the current shape in a **JLabel** in the **SOUTH** region of a **BorderLayout**. The initial shape should default to a circle.

12.17 Create an application that enables the user to paint a picture. The user should be able to choose the shape to draw, the color in which the shape should appear and whether the shape should be filled with color. Use the graphical user interface components we discussed in this chapter, such as **JComboBox**es, **JRadioButton**s and **JCheckBox**es, to allow the user to select various options. The program should provide a **JButton** object that allows the user to erase the window.

12.18 Write a program that uses **System.out.println** statements to print out events as they occur. Provide a **JComboBox** with a minimum of four items. The user should be able to choose an event to "monitor" from the **JComboBox**. When that particular event occurs, display information about the event in a message dialog box. Use method **toString** on the event object to convert it to a string representation.

12.19 Write a program that draws a square. As the mouse moves over the drawing area, repaint the square with the upper-left corner of the square following the exact path of the mouse cursor.

12.20 Modify the program of Fig. 12.19 to incorporate colors. In a separate window, provide a "toolbar" of **JRadioButton** objects that lists the following six colors: red, black, magenta, blue, green and yellow. The toolbar should be implemented as a subclass of **JFrame** called **ToolBarWindow** and should consist of six buttons, each with the appropriate color name. When a new color is selected, drawing should occur in the new color. Determine the currently selected color in the **mousePressed** event handler of the main window by calling a public method **getCurrentColor** on the **ToolBarWindow**. [Note: In Chapter 13, we discuss how to combine GUI components and drawing, using separate **JPanel**s for each. This provides programs with more flexibility in laying out the components and drawing.]

12.21 Write a program that plays "guess the number" as follows: Your program chooses the number to be guessed by selecting an integer at random in the range 1–1000. The program then displays in a label:

```
I have a number between 1 and 1000 can you guess my number?
Please enter your first guess.
```

A **JTextField** should be used to input the guess. As each guess is input the background color should change to either red or blue. Red indicates that the user is getting "warmer" and blue indicates that the user is getting "colder." A **JLabel** should display either "**Too High**" or "**Too Low**" to help the user zero in on the correct answer. When the user gets the correct answer, "**Correct!**" should be displayed and the **JTextField** used for input should be changed to uneditable. A **JButton** should be provided to allow the user to play the game again. When the **JButton** is clicked, a new random number should be generated and the input **JTextField** changed to editable.

12.22 It is often useful to display the events that occur during the execution of a program to help understand when the events occur and how they are generated. Write a program that enables the user to generate and process every event discussed in this chapter. The program should provide methods from the **ActionListener**, **ItemListener**, **ListSelectionListener**, **MouseListener**, **MouseMotionListener** and **KeyListener** interfaces to display messages when the events occur. Use method **toString** to convert the event objects received in each event handler into a **String** that can be displayed. Method **toString** creates a **String** containing all the information in the event object.

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12.23 Modify your solution to Exercise 12.17 to enable the user to select a font and a font size, then type text into a **`JTextField`**. When the user presses *Enter,* the text should be displayed on the background in the chosen font and size. Modify the program further to allow the user to specify the exact position at which the text should be displayed.

12.24 Write a program that allows the user to select a shape from a **`JComboBox`**, then draws that shape 20 times with random locations and dimensions in method **`paint`**. The first item in the **`JComboBox`** should be the default shape that is displayed the first time **`paint`** is called.

12.25 Modify Exercise 12.24 to draw each of the 20 randomly sized shapes in a randomly selected color. Use all 13 predefined **`Color`** objects in an array of **`Color`**s.

12.26 Modify Exercise 12.25 to allow the user to select the color in which shapes should be drawn from a **`JColorChooser`** dialog.

12.27 Write a program using methods from interface **`MouseListener`** that allows the user to press the mouse button, drag the mouse and release the mouse button. When the mouse is released, draw a rectangle with the appropriate upper-left corner, width and height. (*Hint*: The **`mousePressed`** method should capture the set of coordinates at which the user presses and holds the mouse button initially, and the **`mouseReleased`** method should capture the set of coordinates at which the user releases the mouse button. Both methods should store the appropriate coordinate values. All calculations of the width, height and upper-left corner should be performed by the **`paint`** method before the shape is drawn.)

12.28 Modify Exercise 12.27 to provided a "rubber-banding" effect. As the user drags the mouse, the user should be able to see the current size of the rectangle to know exactly what the rectangle will look like when the mouse button is released. (*Hint*: Method **`mouseDragged`** should perform the same tasks as **`mouseReleased`**.)

12.29 Modify Exercise 12.28 to allow the user to select which shape to draw. A **`JComboBox`** should provide options including at least rectangle, oval, line and rounded rectangle.

12.30 Modify Exercise 12.29 to allow the user to select the drawing color from a **`JColorChooser`** dialog box.

12.31 Modify Exercise 12.30 to allow the user to specify whether a shape should be filled or empty when it is drawn. The user should click a **`JCheckBox`** to indicate filled or empty.

12.32 *(Painting program)* Using the techniques of Exercise 9.28–Exercise 9.29 and Exercise 12.27–Exercise 12.30 and the graphics techniques of Chapter 11, rewrite Exercise 12.31 to allow the user to draw multiple shapes and store each shape in an array of shapes. (If you feel ambitious, investigate the capabilities of class **`Vector`** in Chapter 20.) For this program, create your own classes (like those in the class hierarchy described in Exercise 9.28–Exercise 9.29) from which objects will be created to store each shape the user draws. The classes should store the location, dimensions and color of each shape and should indicate whether the shape is filled or unfilled. Your classes should all derive from a class called **`MyShape`** that has all the common features of every shape type. Every subclass of **`MyShape`** should have its own method **`draw`**, which returns **`void`** and receives a **`Graphics`** object as its argument. When the application window's **`paint`** method is called, it should walk through the array of shapes and display each shape by polymorphically calling the shape's **`draw`** method (passing the **`Graphics`** object as an argument). Each shape's **`draw`** method should know how to draw the shape. As a minimum, your program should provide the following classes: **`MyLine`**, **`MyOval`**, **`MyRect`**, **`MyRoundRect`**. Design the class hierarchy for maximum software reuse, and place all your classes in the package **`shapes`**. Import this package into your program.

12.33 Modify Exercise 12.32 to provide an **Undo** button that can be used repeatedly to undo the last painting operation. If there are no shapes in the array of shapes, the Undo button should be disabled.

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13

Graphical User Interface Components: Part 2

Objectives

- To create and manipulate text areas, sliders, menus, popup menus and windows.
- To be able to create customized **`JPanel`** objects.
- To be able to create a program that can execute as either an applet or an application.
- To be able to change the look-and-feel of a GUI, using Swing's pluggable look-and-feel (PLAF).
- To be able to create a multiple document interface with **`JDesktopPane`** and **`JInternalFrame`**.
- To be able to use advanced layout managers.

I claim not to have controlled events, but confess plainly that events have controlled me.
Abraham Lincoln

A good symbol is the best argument, and is a missionary to persuade thousands.
Ralph Waldo Emerson

Capture its reality in paint!
Paul Cézanne

Outline

13.1 Introduction
13.2 `JTextArea`
13.3 Creating a Customized Subclass of `JPanel`
13.4 Creating a Self-Contained Subclass of `JPanel`
13.5 `JSlider`
13.6 Windows
13.7 Designing Programs that Execute as Applets or Applications
13.8 Using Menus with Frames
13.9 Using `JPopupMenus`
13.10 Pluggable Look-and-Feel
13.11 Using `JDesktopPane` and `JInternalFrame`
13.12 Layout Managers
13.13 `BoxLayout` Layout Manager
13.14 `CardLayout` Layout Manager
13.15 `GridBagLayout` Layout Manager
13.16 `GridBagConstraints` Constants `RELATIVE` and `REMAINDER`
13.17 (Optional Case Study) Thinking About Objects: Model-View-Controller
13.18 (Optional) Discovering Design Patterns: Design Patterns Used in Packages `java.awt` and `javax.swing`
13.18.1 Creational Design Patterns
13.18.2 Structural Design Patterns
13.18.3 Behavioral Design Patterns
13.18.4 Conclusion

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

13.1 Introduction

In this chapter, we continue our study of GUIs. We discuss more advanced components and layout managers and lay the groundwork for building complex GUIs.

We begin our discussion with another text-based GUI component—***`JTextArea`***—which allows multiple lines of text to be displayed or input. We continue with two examples of *customizing class* ***`JPanel`*** in which we discuss issues that relate to painting on Swing GUI components. Next, we illustrate how to design a Java program that can execute as both an applet and an application. An important aspect of any complete GUI is a system of *menus* that enable the user to effectively perform tasks in the program. The next two examples discuss how to create and use menus. The look-and-feel of a Swing GUI can be uniform across all platforms on which the Java program is executed, or the GUI can be

customized by using Swing's *pluggable look-and-feel (PLAF)*. The next example illustrates how to change between Swing's default *metal look-and-feel*, a look-and-feel that simulates *Motif* (a popular UNIX look-and-feel) and one that simulates Microsoft's Windows look-and-feel. Many of today's applications use a *multiple document interface (MDI),* [i.e., a main window (often called the *parent window*) containing other windows (often called *child windows*) to manage several open *documents* in parallel. For example, many e-mail programs allow you to have several e-mail windows open at the same time so you can compose and/or read multiple e-mail messages. The next example discusses Swing's classes that provide support for creating multiple document interfaces. Finally, the chapter finishes with a series of examples discussing several advanced layout managers for organizing graphical user interfaces.

Swing is a large and complex topic. There are many more GUI components and capabilities than can be presented here. Several more Swing GUI components are introduced in the remaining chapters of this book as they are needed. Our book *Advanced Java 2 Platform How to Program* discusses other, more advanced Swing components and capabilities.

13.2 JTextArea

JTextArea**s* provide an area for manipulating multiple lines of text. Like class **JTextField**, class **JTextArea** inherits from ***JTextComponent, which defines common methods for **JTextField**s, **JTextArea**s and several other text-based GUI components.

The application of Fig. 13.1 demonstrates **JTextArea**s. One **JTextArea** displays text that the user can select. The other **JTextArea** is uneditable. Its purpose is to display the text the user selected in the first **JTextArea**. **JTextArea**s do not have action events like **JTextField**s. Often, an *external event*—an event generated by a different GUI component—indicates when to process the text in a **JTextArea**. For example, when typing an e-mail message, you often click a **Send** button to take the text of the message and send it to the recipient. Similarly, when editing a document in a word processor, you normally save the file by selecting a menu item called **Save** or **Save As...**. In this program, the button **Copy >>>** generates the external event that copies the selected text in the left **JTextArea** and displays it in the right **JTextArea**.

```
1  // Fig. 13.1: TextAreaDemo.java
2  // Copying selected text from one text area to another.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class TextAreaDemo extends JFrame {
12    private JTextArea textArea1, textArea2;
13    private JButton copyButton;
14
```

Fig. 13.1 Copying selected text from one text area to another (part 1 of 3).

```
15     // set up GUI
16     public TextAreaDemo()
17     {
18        super( "TextArea Demo" );
19
20        Box box = Box.createHorizontalBox();
21
22        String string = "This is a demo string to\n" +
23           "illustrate copying text\n" +
24           "from one TextArea to \n" +
25           "another TextArea using an\n" + "external event\n";
26
27        // set up textArea1
28        textArea1 = new JTextArea( string, 10, 15 );
29        box.add( new JScrollPane( textArea1 ) );
30
31        // set up copyButton
32        copyButton = new JButton( "Copy >>>" );
33        copyButton.addActionListener(
34
35           // anonymous inner class to handle copyButton event
36           new ActionListener() {
37
38              // set text in textArea2 to selected
39              // text from textArea1
40              public void actionPerformed( ActionEvent event )
41              {
42                 textArea2.setText( textArea1.getSelectedText() );
43              }
44
45           }  // end anonymous inner class
46
47        ); // end call to addActionListener
48
49        box.add( copyButton );
50
51        // set up textArea2
52        textArea2 = new JTextArea( 10, 15 );
53        textArea2.setEditable( false );
54        box.add( new JScrollPane( textArea2 ) );
55
56        // add box to content pane
57        Container container = getContentPane();
58        container.add( box );   // place in BorderLayout.CENTER
59
60        setSize( 425, 200 );
61        setVisible( true );
62     }
63
64     // execute application
65     public static void main( String args[] )
66     {
67        TextAreaDemo application = new TextAreaDemo();
```

Fig. 13.1 Copying selected text from one text area to another (part 2 of 3).

```
68
69          application.setDefaultCloseOperation(
70             JFrame.EXIT_ON_CLOSE );
71       }
72
73    }  // end class TextAreaDemo
```

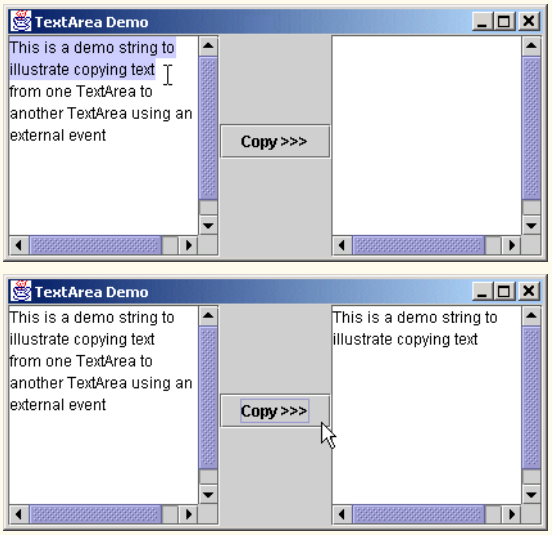


Fig. 13.1 Copying selected text from one text area to another (part 3 of 3).

Look-and-Feel Observation 13.1

Often an external event determines when the text in a ***JTextArea*** *should be processed.*

In the constructor method (lines 16–62), line 20 creates a ***Box*** *container* (package **javax.swing**) for organizing the GUI components. Class **Box** is a subclass of **Container** that uses a ***BoxLayout*** layout manager to arrange the GUI components either horizontally or vertically. Section 13.13 discusses **BoxLayout** in detail. Class **Box** provides static method ***createHorizontalBox*** to create a **Box** that arranges components from left to right in the order that the components are attached.

The application instantiates **JTextArea** objects **textArea1** (line 28) and **textArea2** (line 52). Each **JTextArea** has **10** visible rows and **15** visible columns. Line 28 specifies that **string** should be displayed as the default **JTextArea** content. A **JTextArea** does not provide scrollbars if it cannot display its complete contents. For this reason, line 29 creates a **JScrollPane** object, initializes it with **textArea1** and attaches it to container **box**. By default, horizontal and vertical scrollbars will appear as necessary.

Lines 32–49 instantiate **JButton** object **copyButton** with the label "**Copy >>>**," create an anonymous inner class to handle **copyButton**'s **ActionEvent** and add **copyButton** to container **box**. This button provides the external event that determines when the program should copy the selected text in **textArea1** to **textArea2**. When the user clicks **copyButton**, line 42 in **actionPerformed** indicates that method

getSelectedText (inherited into **JTextArea** from **JTextComponent**) should return the *selected text* from **textArea1**. The user selects text by dragging the mouse over the desired text to highlight it. Method **setText** changes the text in **textArea2** to the **String** that method **getSelectedText** returns.

Lines 52–54 create **textArea2** and add it to container **box**. Lines 57–58 obtain the content pane for the window and add **box** to the content pane. Remember that the default layout of the content pane is a **BorderLayout** and that the add method attaches its argument to the **CENTER** of the **BorderLayout** if method **add** does not specify the region.

It is sometimes desirable when text reaches the right side of a **JTextArea** to have the text wrap to the next line. This is referred to as *automatic word wrap*.

Look-and-Feel Observation 13.2

*To provide automatic word wrap functionality for a **JTextArea**, invoke **JTextArea** method **setLineWrap** with a **true** argument.*

This example uses a **JScrollPane** to provide scrolling functionality for a **JTextArea**. By default, **JScrollPane** provides scrollbars only if they are required. You can set the horizontal and vertical *scrollbar policies* for the **JScrollPane** when a **JScrollPane** is constructed or with methods ***setHorizontalScrollBarPolicy*** and ***setVerticalScrollBarPolicy*** of class **JScrollPane** at any time. Class **JScrollPane** provides the constants

```
JScrollPane.VERTICAL_SCROLLBAR_ALWAYS
JScrollPane.HORIZONTAL_SCROLLBAR_ALWAYS
```

to indicate that a scrollbar should always appear, constants

```
JScrollPane.VERTICAL_SCROLLBAR_AS_NEEDED
JScrollPane.HORIZONTAL_SCROLLBAR_AS_NEEDED
```

to indicate that a scrollbar should appear only if necessary, and constants

```
JScrollPane.VERTICAL_SCROLLBAR_NEVER
JScrollPane.HORIZONTAL_SCROLLBAR_NEVER
```

to indicate that a scrollbar should never appear. If the horizontal scrollbar policy is set to **JScrollPane.HORIZONTAL_SCROLLBAR_NEVER**, a **JTextArea** attached to the **JScrollPane** will exhibit automatic word wrap behavior.

13.3 Creating a Customized Subclass of JPanel

In Chapter 12, we saw that **JPanel**s can aggregate a set of GUI components for layout purposes. **JPanel**s are quite flexible. Some of their many uses include creating *dedicated drawing areas* and creating areas that receive mouse events. Programs often extend class **JPanel** to create new components. Our next example uses a **JPanel** to create a dedicated drawing area. Dedicated drawing areas help separate drawing from the rest of your graphical user interface. This can be beneficial in Swing graphical user interfaces. If graphics and Swing GUI components are not displayed in the correct order, it is possible that the GUI components will not display correctly. For example, to ensure that graphics and GUI both display correctly, we can separate the GUI and the graphics by creating dedicated drawing areas as subclasses of **JPanel**.

Look-and-Feel Observation 13.3

Combining graphics and Swing GUI components can lead to incorrect display of the graphics, the GUI components or both. Using ***JPanel****s for drawing can eliminate this problem by providing a dedicated area for graphics.*

Swing components that inherit from class **JComponent** contain method ***paintComponent*** that helps them draw properly in the context of a Swing GUI. When customizing a **JPanel** for use as a dedicated drawing area, the subclass should override method **paintComponent** and call the superclass version of **paintComponent** as the first statement in the body of the overridden method. This ensures that painting occurs in the proper order and that Swing's painting mechanism remains intact. An important part of this mechanism is that subclasses of **JComponent** support *transparency*, which can be set with method ***setOpaque*** (a **false** argument indicates the component is transparent). To paint a component correctly, the program must determine whether the component is transparent. The code that performs this check is in the superclass version of **paintComponent**. When a component is transparent, **paintComponent** will not clear the component's background when the program paints the component. When a component is *opaque*, **paintComponent** clears the background before continuing the painting operation. If the superclass version of **paintComponent** is not called, an opaque GUI component typically will not display correctly on the user interface. Also, if the superclass version is called after performing the customized drawing statements, the results typically will be erased.

Look-and-Feel Observation 13.4

When overriding a ***JComponent****'s* ***paintComponent*** *method, the first statement in the body should always be a call to the superclass's original version of the method.*

Common Programming Error 13.1

When overriding a ***JComponent****'s* ***paintComponent*** *method, not calling the superclass's original version of* ***paintComponent*** *might prevent the GUI component from displaying properly on the GUI.*

Common Programming Error 13.2

When overriding a ***JComponent****'s* ***paintComponent*** *method, calling the superclass's* ***paintComponent*** *method after other drawing is performed erases the other drawings.*

Classes **JFrame** and **JApplet** are not subclasses of **JComponent**; therefore, they do not contain method **paintComponent**. To draw directly on subclasses of **JFrame** and **JApplet**, override method **paint**.

Look-and-Feel Observation 13.5

Calling ***repaint*** *for a Swing GUI component indicates that the component should be painted as soon as possible. The background of the GUI component is cleared only if the component is opaque. Most Swing components are transparent by default.* ***JComponent*** *method* ***setOpaque*** *can be passed a* ***boolean*** *argument indicating whether the component is opaque (****true****) or transparent (****false****). The GUI components of package* ***java.awt*** *are different from Swing components, in that* ***repaint*** *results in a call to* ***Component*** *method* ***update*** *(which clears the component's background) and* ***update*** *calls method* ***paint*** *(rather than* ***paintComponent****).*

The program of Fig. 13.2 and Fig. 13.3 demonstrates a customized subclass of **JPanel**. Class **CustomPanel** (Fig. 13.2) has its own **paintComponent** method that draws a circle or a square, depending on the value passed to **CustomPanel**'s **draw** method. For this purpose, **CustomPanel** line 11 defines constants that enable the program to specify the shape a **CustomPanel** draws on itself with each call to its **paintComponent** method. Class **CustomPanelTest** (Fig. 13.3) creates a **CustomPanel** and a GUI that enable the user to choose which shape to draw.

Class **CustomPanel** contains one instance variable, **shape**, that stores an integer representing the shape to draw. Method **paintComponent** (lines 15–23) draws a shape on the panel. If **shape** is **CIRCLE**, **Graphics** method **fillOval** draws a solid circle. If **shape** is **SQUARE**, **Graphics** method **fillRect** draws a solid square. Method **draw** (lines 26–30) sets instance variable **shape** and calls **repaint** to refresh the **CustomPanel** object. Note that calling **repaint** (which is really **this.repaint()**) for the **CustomPanel** schedules a painting operation for the **CustomPanel**. Method **paintComponent** will be called to repaint the **CustomPanel** and draw the appropriate shape.

```
1  // Fig. 13.2: CustomPanel.java
2  // A customized JPanel class.
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class CustomPanel extends JPanel {
11    public final static int CIRCLE = 1, SQUARE = 2;
12    private int shape;
13
14    // use shape to draw an oval or rectangle
15    public void paintComponent( Graphics g )
16    {
17       super.paintComponent( g );
18
19       if ( shape == CIRCLE )
20          g.fillOval( 50, 10, 60, 60 );
21       else if ( shape == SQUARE )
22          g.fillRect( 50, 10, 60, 60 );
23    }
24
25    // set shape value and repaint CustomPanel
26    public void draw( int shapeToDraw )
27    {
28       shape = shapeToDraw;
29       repaint();
30    }
31
32 }  // end class CustomPanel
```

Fig. 13.2 Defining a custom drawing area by subclassing **JPanel**.

Class **CustomPanelTest** (Fig. 13.3) instantiates a **CustomPanel** object (line 22 of its constructor) and sets its background color to green, so the **CustomPanel** area is visible on the application. Next, the constructor instantiates **JButton** objects **squareButton** and **circleButton**. Lines 27–40 register an event handler for **squareButton**'s **ActionEvent**. Lines 43–56 register an event handler for **circleButton**'s **ActionEvent**. Lines 35 and 51 each call **CustomPanel** method **draw**. In each case, the appropriate constant (**CustomPanel.SQUARE** or **CustomPanel.CIRCLE**) is passed as an argument to indicate which shape to draw.

```
1  // Fig. 13.3: CustomPanelTest.java
2  // Using a customized Panel object.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class CustomPanelTest extends JFrame {
12    private JPanel buttonPanel;
13    private CustomPanel myPanel;
14    private JButton circleButton, squareButton;
15
16    // set up GUI
17    public CustomPanelTest()
18    {
19       super( "CustomPanel Test" );
20
21       // create custom drawing area
22       myPanel = new CustomPanel();
23       myPanel.setBackground( Color.green );
24
25       // set up squareButton
26       squareButton = new JButton( "Square" );
27       squareButton.addActionListener(
28
29          // anonymous inner class to handle squareButton events
30          new ActionListener() {
31
32             // draw a square
33             public void actionPerformed( ActionEvent event )
34             {
35                myPanel.draw( CustomPanel.SQUARE );
36             }
37
38          }  // end anonymous inner class
39
40       ); // end call to addActionListener
41
42       circleButton = new JButton( "Circle" );
```

Fig. 13.3 Drawing on a customized subclass of class **JPanel** (part 1 of 2).

```
43          circleButton.addActionListener(
44
45             // anonymous inner class to handle circleButton events
46             new ActionListener() {
47
48                // draw a circle
49                public void actionPerformed( ActionEvent event )
50                {
51                   myPanel.draw( CustomPanel.CIRCLE );
52                }
53
54             }  // end anonymous inner class
55
56          ); // end call to addActionListener
57
58          // set up panel containing buttons
59          buttonPanel = new JPanel();
60          buttonPanel.setLayout( new GridLayout( 1, 2 ) );
61          buttonPanel.add( circleButton );
62          buttonPanel.add( squareButton );
63
64          // attach button panel & custom drawing area to content pane
65          Container container = getContentPane();
66          container.add( myPanel, BorderLayout.CENTER );
67          container.add( buttonPanel, BorderLayout.SOUTH );
68
69          setSize( 300, 150 );
70          setVisible( true );
71       }
72
73       // execute application
74       public static void main( String args[] )
75       {
76          CustomPanelTest application = new CustomPanelTest();
77
78          application.setDefaultCloseOperation(
79             JFrame.EXIT_ON_CLOSE );
80       }
81
82    }  // end class CustomPanelTest
```

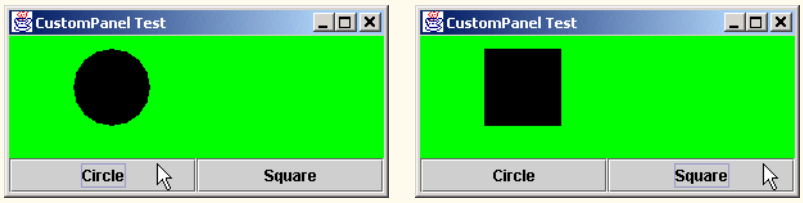


Fig. 13.3 Drawing on a customized subclass of class **`JPanel`** (part 2 of 2).

For layout of the buttons, **`CustomPanelTest`** creates **`JPanel buttonPanel`** with a **`GridLayout`** of one row and two columns (lines 59–60), then attaches the buttons to the panel (lines 61–62). Finally, **`CustomPanelTest`** adds **`myPanel`** to the **`CENTER`**

region of the content pane and adds **buttonPanel** to the **SOUTH** region of the content pane. Note that the **BorderLayout** expands **myPanel** to fill the center region.

13.4 Creating a Self-Contained Subclass of JPanel

JPanels do not support conventional events supported by other GUI components, like buttons, text fields and windows. However, **JPanel**s are capable of recognizing such lower-level events as mouse events and key events. The program of Fig. 13.4 and Fig. 13.5 allows the user to draw an oval on a subclass of **JPanel** by dragging the mouse across the panel. Class **SelfContainedPanel** (Fig. 13.4) listens for its own mouse events and draws an oval on itself in response to those mouse events. The location and size of the oval are determined from the coordinates of the mouse events. The coordinates at which the user presses the mouse button specify the starting point for the oval's bounding box. As the user drags the mouse, the coordinates of the mouse pointer specify another point. Together, the program uses these points to calculate the upper-left *x*-*y* coordinate, the width and the height of the oval's bounding box. The size of the oval changes continuously while the user drags the mouse. When the user releases the mouse button, the program calculates the final bounding box for the oval and draws the oval. Line 4 of Fig. 13.4 indicates that class **SelfContainedPanel** is in package **com.deitel.jhtp4.ch13** for future reuse. Class **SelfContainedPanelTest** imports **SelfContainedPanel** at line 13 of Fig. 13.5.

```
1  // Fig. 13.4: SelfContainedPanel.java
2  // A self-contained JPanel class that
3  // handles its own mouse events.
4  package com.deitel.jhtp4.ch13;
5
6  // Java core packages
7  import java.awt.*;
8  import java.awt.event.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class SelfContainedPanel extends JPanel {
14    private int x1, y1, x2, y2;
15
16    // set up mouse event handling for SelfContainedPanel
17    public SelfContainedPanel()
18    {
19       // set up mouse listener
20       addMouseListener(
21
22          // anonymous inner class for mouse pressed and
23          // released event handling
24          new MouseAdapter() {
25
26             // handle mouse press event
27             public void mousePressed( MouseEvent event )
28             {
29                x1 = event.getX();
```

Fig. 13.4 Customized subclass of **JPanel** that processes mouse events (part 1 of 2).

```
30                y1 = event.getY();
31             }
32
33             // handle mouse release event
34             public void mouseReleased( MouseEvent event )
35             {
36                x2 = event.getX();
37                y2 = event.getY();
38                repaint();
39             }
40
41          }  // end anonymous inner class
42
43       ); // end call to addMouseListener
44
45       // set up mouse motion listener
46       addMouseMotionListener(
47
48          // anonymous inner class to handle mouse drag events
49          new MouseMotionAdapter() {
50
51             // handle mouse drag event
52             public void mouseDragged( MouseEvent event )
53             {
54                x2 = event.getX();
55                y2 = event.getY();
56                repaint();
57             }
58
59          }  // end anonymous inner class
60
61       ); // end call to addMouseMotionListener
62
63    }  // end constructor
64
65    // return preferred width and height of SelfContainedPanel
66    public Dimension getPreferredSize()
67    {
68       return new Dimension( 150, 100 );
69    }
70
71    // paint an oval at the specified coordinates
72    public void paintComponent( Graphics g )
73    {
74       super.paintComponent( g );
75
76       g.drawOval( Math.min( x1, x2 ), Math.min( y1, y2 ),
77          Math.abs( x1 - x2 ), Math.abs( y1 - y2 ) );
78    }
79
80 }  // end class SelfContainedPanel
```

Fig. 13.4 Customized subclass of **`JPanel`** that processes mouse events (part 2 of 2).

Class **SelfContainedPanel** (Fig. 13.4) extends class **JPanel**. Instance variables **x1** and **y1** store the initial coordinates where the **mousePressed** event occurs on the **SelfContainedPanel**. Instance variables **x2** and **y2** store the coordinates where the user drags the mouse or releases the mouse button. All the coordinates are with respect to the upper-left corner of the **SelfContainedPanel**.

Look-and-Feel Observation 13.6

Drawing on any GUI component is performed with coordinates that are measured from the upper-left corner (0, 0) of that GUI component.

The **SelfContainedPanel** constructor (lines 17–63) uses methods **addMouseListener** and **addMouseMotionListener** to register anonymous inner-class objects to handle mouse events and mouse motion events for the **SelfContainedPanel**. Only **mousePressed** (lines 27–31), **mouseReleased** (lines 34–39) and **mouseDragged** (lines 52–57) are overridden to perform tasks. The other mouse event-handling methods are inherited by the anonymous inner classes from the adapter classes **MouseAdapter** and **MouseMotionAdapter**.

By extending class **JPanel**, we are actually creating a new GUI component. Layout managers often use a GUI component's ***getPreferredSize*** method (inherited from class **java.awt.Component**) to determine the preferred width and height of a component when laying out that component as part of a GUI. If a new component has a preferred width and height, it should override method **getPreferredSize** (lines 66–69) to return that width and height as an object of class ***Dimension*** (package **java.awt**).

Look-and-Feel Observation 13.7

*The default size of a **JPanel** object is 10 pixels wide and 10 pixels tall.*

Look-and-Feel Observation 13.8

*When subclassing **JPanel** (or any other **JComponent**), override method **getPreferredSize** if the new component should have a specific preferred width and height.*

Method **paintComponent** (lines 72–78) draws an oval, using the current values of instance variables **x1**, **y1**, **x2** and **y2**. The width, height and upper-left corner are determined by the pressing and holding of the mouse button, the dragging of the mouse and releasingof the mouse button on the **SelfContainedPanel** drawing area.

The initial coordinates **x1** and **y1** on the **SelfContainedPanel** drawing area are captured in method **mousePressed** (lines 27–31). As the user drags the mouse after the initial **mousePressed** operation, the program generates a series of calls to **mouseDragged** (lines 52–57) while the user continues to hold the mouse button and move the mouse. Each call captures in variables **x2** and **y2** the current location of the mouse with respect to the upper-left corner of the **SelfContainedPanel** and calls **repaint** to draw the current version of the oval. Drawing is strictly confined to the **SelfContainedPanel**, even if the user drags outside the **SelfContainedPanel** drawing area. Anything drawn off the **SelfContainedPanel** is *clipped*—pixels are not displayed outside the bounds of the **SelfContainedPanel**.

The calculations provided in method **paintComponent** determine the proper upper-left corner, using method **Math.min** twice to find the smaller *x* coordinate and *y* coordinate. The oval's width and height must be positive values or the oval is not displayed.

Method **Math.abs** gets the absolute value of the subtractions **x1 - x2** and **y1 - y2** that determine the width and height of the oval's bounding rectangle, respectively. When the calculations are complete, **paintComponent** draws the oval. The call to the superclass version of **paintComponent** at the beginning of the method guarantees that the previous oval displayed on the **SelfContainedPanel** is erased before the new one is displayed.

Look-and-Feel Observation 13.9

*Most Swing GUI components can be transparent or opaque. If a Swing GUI component is opaque, when its **paintComponent** method is called, its background will be cleared. Otherwise, its background will not be cleared. Only opaque components can display a customized background color.*

Look-and-Feel Observation 13.10

***JPanel** objects are opaque by default.*

When the user releases the mouse button, method **mouseReleased** (lines 34–39) captures in variables **x2** and **y2** the final location of the mouse and invokes **repaint** to draw the final version of the oval.

Class **SelfContainedPanelTest**'s constructor (lines 21–57 of Fig. 13.5) creates an instance of class **SelfContainedPanel** (line 24) and sets the background color (line 25) of the **SelfContainedPanel** to yellow so that its area is visible against the background of the application window.

```
1  // Fig. 13.5: SelfContainedPanelTest.java
2  // Creating a self-contained subclass of JPanel
3  // that processes its own mouse events.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 // Deitel packages
13 import com.deitel.jhtp4.ch13.SelfContainedPanel;
14
15 public class SelfContainedPanelTest extends JFrame {
16    private SelfContainedPanel myPanel;
17
18
19    // set up GUI and mouse motion event handlers for
20    // application window
21    public SelfContainedPanelTest()
22    {
23       // set up a SelfContainedPanel
24       myPanel = new SelfContainedPanel();
25       myPanel.setBackground( Color.yellow );
26
27       Container container = getContentPane();
```

Fig. 13.5 Capturing mouse events with a **JPanel** (part 1 of 3).

```
28          container.setLayout( new FlowLayout() );
29          container.add( myPanel );
30
31          // set up mouse motion event handling
32          addMouseMotionListener(
33
34             // anonymous inner class for mouse motion event handling
35             new MouseMotionListener() {
36
37                // handle mouse drag event
38                public void mouseDragged( MouseEvent event )
39                {
40                   setTitle( "Dragging: x=" + event.getX() +
41                      "; y=" + event.getY() );
42                }
43
44                // handle mouse move event
45                public void mouseMoved( MouseEvent event )
46                {
47                   setTitle( "Moving: x=" + event.getX() +
48                      "; y=" + event.getY() );
49                }
50
51             }  // end anonymous inner class
52
53          ); // end call to addMouseMotionListener
54
55          setSize( 300, 200 );
56          setVisible( true );
57       }
58
59       // execute application
60       public static void main( String args[] )
61       {
62          SelfContainedPanelTest application =
63             new SelfContainedPanelTest();
64
65          application.setDefaultCloseOperation(
66             JFrame.EXIT_ON_CLOSE );
67       }
68
69    }  // end class SelfContainedPanelTest
```

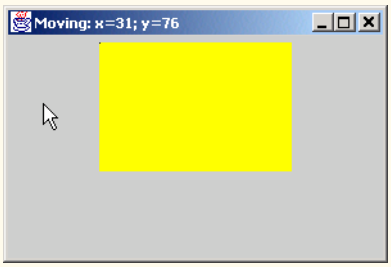


Fig. 13.5 Capturing mouse events with a **`JPanel`** (part 2 of 3).

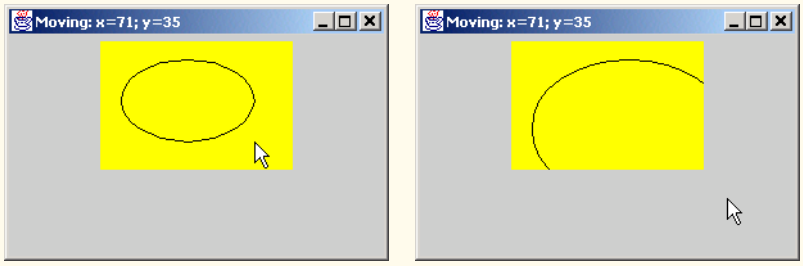


Fig. 13.5 Capturing mouse events with a **`JPanel`** (part 3 of 3).

We would like this program to distinguish between mouse motion events on the **`SelfContainedPanel`** and mouse motion events on the application window, so lines 32–53 register an object of an anonymous inner class to handle the application's mouse motion events. Event handlers **`mouseDragged`** (lines 38–42) and **`mouseMoved`** (lines 45–49) use method **`setTitle`** (inherited from class **`java.awt.Frame`**) to display a **`String`** in the window's title bar indicating the *x*-*y* coordinate where the mouse motion event occurred.

When executing this program, try dragging from the background of the application window into the **`SelfContainedPanel`** area to see that the drag events are sent to the application window rather than the **`SelfContainedPanel`**. Then, start a new drag operation in the **`SelfContainedPanel`** area and drag out to the background of the application window to see that the drag events are sent to the **`SelfContainedPanel`** rather than to the application window.

Look-and-Feel Observation 13.11

A mouse drag operation begins with a mouse-pressed event. All subsequent mouse drag events (until the user releases the mouse button) are sent to the GUI component that received the original mouse-pressed event.

13.5 `JSlider`

`JSlider``s` enable the user to select from a range of integer values. Class ***`JSlider`*** inherits from **`JComponent`**. Figure 13.6 shows a horizontal **`JSlider`** with *tick marks* and the *thumb* that allows the user to select a value. **`JSlider`**s are highly customizable in that they can display *major tick marks*, *minor tick marks* and labels for the tick marks. They also support *snap-to ticks* where positioning the thumb between two tick marks causes the thumb to *snap* to the closest tick mark.

Fig. 13.6 Horizontal **`JSlider`** component.

Most Swing GUI components support user interactions through the mouse and the keyboard. For example, if a **JSlider** has the *focus* (i.e., it is the currently selected GUI component in the user interface), the *left arrow key* and *right arrow key* cause the thumb of the **JSlider** to decrease or increase by 1, respectively. The *down arrow key* and *up arrow key* also cause the thumb of the **JSlider** to decrease or increase by 1, respectively. The *PgDn key* (page down) and *PgUp key* (page up) cause the thumb of the **JSlider** to decrease or increase by *block increments* of one-tenth of the range of values, respectively. The *Home key* moves the thumb to the minimum value of the **JSlider** and the *End key* moves the thumb to the maximum value of the **JSlider**.

Look-and-Feel Observation 13.12

Most Swing components support user interactions through the mouse and the keyboard.

JSliders have either a *horizontal orientation* or a *vertical orientation*. For a horizontal **JSlider**, the minimum value is at the extreme left and the maximum value is at the extreme right of the **JSlider**. For a vertical **JSlider**, the minimum value is at the extreme bottom and the maximum value is at the extreme top of the **JSlider**. The relative position of the thumb indicates the current value of the **JSlider**.

Look-and-Feel Observation 13.13

*The minimum and maximum value positions on a **JSlider** can be switched by calling the **JSlider** method **setInverted** with boolean argument **true**.*

The program of Fig. 13.7 and Fig. 13.8 allows the user to size a circle drawn on a subclass of **JPanel** called **OvalPanel** (Fig. 13.7). The user specifies the diameter of the circle with a horizontal **JSlider**. Application class **SliderDemo** (Fig. 13.8) creates the **JSlider** that controls the diameter of the circle. Class **OvalPanel** is a subclass of **JPanel** that knows how to draw a circle on itself, using its own instance variable **diameter** to determine the diameter of the circle—the **diameter** is used as the width and height of the bounding box in which the circle is displayed. The **diameter** value is set when the user interacts with the **JSlider**. The event handler calls method **setDiameter** in class **OvalPanel** to set the **diameter** and calls **repaint** to draw the new circle. The **repaint** call results in a call to **OvalPanel**'s **paintComponent** method.

Class **OvalPanel** (Fig. 13.7) contains a **paintComponent** method (lines 14–19) that draws a filled oval (a circle in this example), a **setDiameter** method (lines 22–28) that changes the **diameter** of the circle and **repaint**s the **OvalPanel**, a **getPreferredSize** method (lines 31–34) that defines the preferred width and height of an **OvalPanel** and a **getMinimumSize** method (lines 37–40) that defines the minimum width and height of an **OvalPanel**.

Look-and-Feel Observation 13.14

*If a new GUI component has a minimum width and height (i.e., smaller dimensions would render the component ineffective on the display), override method **getMinimumSize** to return the minimum width and height as an instance of class **Dimension**.*

Look-and-Feel Observation 13.15

*For many GUI components, method **getMinimumSize** is defined to return the result of a call to that component's **getPreferredSize** method.*

```
1  // Fig. 13.7: OvalPanel.java
2  // A customized JPanel class.
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class OvalPanel extends JPanel {
11    private int diameter = 10;
12
13    // draw an oval of the specified diameter
14    public void paintComponent( Graphics g )
15    {
16       super.paintComponent( g );
17
18       g.fillOval( 10, 10, diameter, diameter );
19    }
20
21    // validate and set diameter, then repaint
22    public void setDiameter( int newDiameter )
23    {
24       // if diameter invalid, default to 10
25       diameter = ( newDiameter >= 0 ? newDiameter : 10 );
26
27       repaint();
28    }
29
30    // used by layout manager to determine preferred size
31    public Dimension getPreferredSize()
32    {
33       return new Dimension( 200, 200 );
34    }
35
36    // used by layout manager to determine minimum size
37    public Dimension getMinimumSize()
38    {
39       return getPreferredSize();
40    }
41
42 }  // end class OvalPanel
```

Fig. 13.7 Custom subclass of **JPanel** for drawing circles of a specified diameter.

Class **SliderDemo**'s constructor (lines 17–54 of Fig. 13.8) instantiates **OvalPanel** object **myPanel** and sets its background color (lines 22–23). Lines 26–27 instantiate **JSlider** object **diameterSlider** to control the diameter of the circle drawn on the **OvalPanel**. The orientation of **diameterSlider** is **HORIZONTAL** (a constant in interface **SwingConstants**). The second and third constructor arguments to the **JSlider** constructor indicate the minimum and maximum integer values in the range of values for this **JSlider**. The last constructor argument indicates that the initial value of the **JSlider** (i.e., where the thumb is displayed) should be **10**.

```
1  // Fig. 13.8: SliderDemo.java
2  // Using JSliders to size an oval.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10 import javax.swing.event.*;
11
12 public class SliderDemo extends JFrame {
13    private JSlider diameterSlider;
14    private OvalPanel myPanel;
15
16    // set up GUI
17    public SliderDemo()
18    {
19       super( "Slider Demo" );
20
21       // set up OvalPanel
22       myPanel = new OvalPanel();
23       myPanel.setBackground( Color.yellow );
24
25       // set up JSlider to control diameter value
26       diameterSlider =
27          new JSlider( SwingConstants.HORIZONTAL, 0, 200, 10 );
28       diameterSlider.setMajorTickSpacing( 10 );
29       diameterSlider.setPaintTicks( true );
30
31       // register JSlider event listener
32       diameterSlider.addChangeListener(
33
34          // anonymous inner class to handle JSlider events
35          new ChangeListener() {
36
37             // handle change in slider value
38             public void stateChanged( ChangeEvent e )
39             {
40                myPanel.setDiameter( diameterSlider.getValue() );
41             }
42
43          }  // end anonymous inner class
44
45       ); // end call to addChangeListener
46
47       // attach components to content pane
48       Container container = getContentPane();
49       container.add( diameterSlider, BorderLayout.SOUTH );
50       container.add( myPanel, BorderLayout.CENTER );
51
52       setSize( 220, 270 );
```

Fig. 13.8 Using a **`JSlider`** to determine the diameter of a circle (part 1 of 2).

```
53          setVisible( true );
54       }
55
56       // execute application
57       public static void main( String args[] )
58       {
59          SliderDemo application = new SliderDemo();
60
61          application.setDefaultCloseOperation(
62             JFrame.EXIT_ON_CLOSE );
63       }
64
65    }  // end class SliderDemo
```

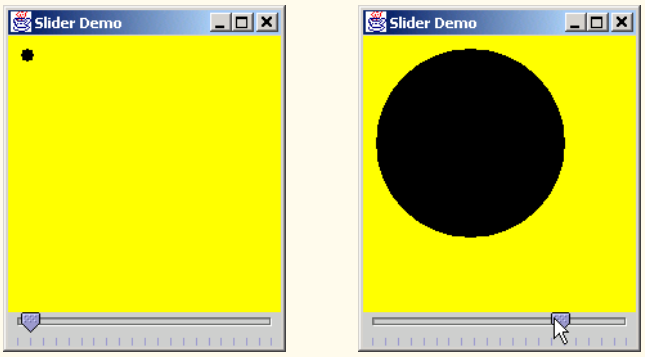


Fig. 13.8 Using a **JSlider** to determine the diameter of a circle (part 2 of 2).

Lines 28–29 customize the appearance of the **JSlider**. Method ***setMajorTickSpacing*** indicates that each tick mark represents 10 values in the range of values supported by the **JSlider**. Method ***setPaintTicks*** with a **true** argument indicates that the tick marks should be displayed (they are not displayed by default). See the **JSlider** on-line documentation for more information on methods that are used to customize a **JSlider**'s appearance.

JSliders generate ***ChangeEvent***s (package **javax.swing.event**) when the user interacts with a **JSlider**. An object of a class that implements interface ***ChangeListener*** (package **javax.swing.event**) and defines method ***stateChanged*** can respond to **ChangeEvent**s. Lines 32–45 register an object of an anonymous inner class that implements **ChangeListener** to handle **diameterSlider**'s events. When method **stateChanged** is called in response to a user interaction, it calls **myPanel**'s **setDiameter** method and passes the current value of the **JSlider** as an argument. Method ***getValue*** of class ***JSlider*** returns the current thumb position.

13.6 Windows

From Chapter 9 to this chapter, most applications have used an instance of a subclass of **JFrame** as the application window. In this section, we discuss several important issues regarding **JFrame**s.

A **JFrame** is a *window* with a *title bar* and a *border*. Class **JFrame** is a subclass of **java.awt.Frame** (which is a subclass of **java.awt.Window**). As such, **JFrame** is one of the few Swing GUI components that is not a lightweight GUI component. Unlike most Swing components, **JFrame** is not written completely in Java. In fact, when you display a window from a Java program, the window is provided by the local platform's set of GUI components—the window will look like all other windows displayed on that platform. When a Java program executes on a Macintosh and displays a window, the window's title bar and borders will look like other Macintosh applications. When a Java program executes on Microsoft Windows and displays a window, the window's title bar and borders will look like other Microsoft Windows applications. And when a Java program executes on a Unix platform and displays a window, the window's title bar and borders will look like other Unix applications on that platform.

Class **JFrame** supports three operations when the user closes the window. By default, a window is hidden (i.e., removed from the screen) when the user closes a window. This can be controlled with **JFrame** method **setDefaultCloseOperation**. Interface **WindowConstants** (package **javax.swing**) defines three constants for use with this method—**DISPOSE_ON_CLOSE**, **DO_NOTHING_ON_CLOSE** and **HIDE_ON_CLOSE** (the default). Most platforms only allow a limited number of windows to be displayed on the screen. As such, a window is a valuable resource that should be given back to the system when it is no longer needed. Class **Window** (an indirect superclass of **JFrame**) defines method **dispose** for this purpose. When a **Window** is no longer needed in an application, you should explicitly **dispose** of the **Window**. This can be done by calling the **Window**'s **dispose** method or by calling method **setDefaultCloseOperation** with the argument **WindowConstants.DISPOSE_ON_CLOSE**. Also, terminating an application will return window resources to the system. Setting the default close operation to **DO_NOTHING_ON_CLOSE** indicates that you will determine what to do when the user indicates that the window should be closed.

Software Engineering Observation 13.1

Windows are a valuable system resource that should be returned to the system when they are no longer needed.

By default, a window is not displayed on the screen until the program invokes the window's **setVisible** method (inherited from class **java.awt.Component**) with a **true** argument or invokes the window's **show** method, which takes no arguments. Also, a window's size should be set with a call to method **setSize** (inherited from class **java.awt.Component**). The position of a window when it appears on the screen is specified with method **setLocation** (inherited from class **java.awt.Component**).

Common Programming Error 13.3

*Forgetting to call method **show** or method **setVisible** on a window is a run-time logic error; the window is not displayed.*

Common Programming Error 13.4

*Forgetting to call the **setSize** method on a window is a run-time logic error—only the title bar appears.*

All windows generate *window events* when the user manipulates the window. Event listeners are registered for window events with method **addWindowListener** of class

Window. Interface ***WindowListener*** (implemented by window event listeners) provides seven methods for handling window events—***windowActivated*** (called when the user makes a window the active window), ***windowClosed*** (called after the window is closed), ***windowClosing*** (called when the user initiates closing of the window), ***windowDeactivated*** (called when the user makes another window the active window), ***windowIconified*** (called when the user minimizes a window), ***windowDeiconified*** (called when the user restores a window from being minimized) and ***windowOpened*** (called when a program first displays a window on the screen).

Most windows have an icon at the top-left or top-right corner that enables a user to close the window and terminate a program. Most windows also have an icon in the upper-left corner of the window that displays a menu when the user clicks the icon. This menu normally contains a **Close** option to close the window and several other options for manipulating the window.

13.7 Designing Programs that Execute as Applets or Applications

It is sometimes desirable to design a Java program that can execute both as a stand-alone application and as an applet in a Web browser. Such a program can be used to provide the same functionality to users worldwide by making the applet available for download via Web and can be installed on a computer as a stand-alone application. The next example discusses how to create a small program that can execute both as an applet and as an application. [*Note*: In Chapter 16 and Chapter 17, we discuss several issues that make applets different from applications and security restrictions placed on applets that prevent certain application features from working in an applet.]

Frequently, programs use **JFrame**s to create *GUI-based applications*. The **JFrame** provides the space in which the application GUI appears. When the user closes the **JFrame**, the application terminates. In this section, we demonstrate how to convert an applet into a GUI-based application. The program of Fig. 13.9 presents an applet that also can be executed as an application.

Software Engineering Observation 13.2

When designing a program to execute as both an applet and an application, begin by defining it as an applet, because applets have limitations due to security restrictions imposed on them by Web browsers. If the program executes properly as an applet, it can be made to work properly as an application. However, the reverse is not always true.

Our applet class **DrawShapes** presents the user with three buttons which, when pressed, cause an instance of class **DrawPanel** (lines 121–126) to draw a random line, rectangle or oval (depending on which button is pressed). The applet does not contain any new features as far as GUI components, layouts or drawing are concerned. The only new feature is that the **DrawShapes** class now also contains a **main** method (lines 60–99) that can be used to execute the program as an application. We discuss this method in detail below.

The HTML document that loads the applet into the **appletviewer** or a Web browser specifies the applet's width and height as 300 and 200, respectively. When the program executes as an application with the **java** interpreter, you can supply arguments to the program (called *command-line arguments*) that specify the width and height of the application window. For example, the command

```
java DrawShapes 600 400
```

contains two command-line arguments—600 and 400—that specify the width and height of the application window. Java passes the command-line arguments to **main** as the array of **String**s called ***args***, which we have declared in the parameter list of every application's **main** method, but not used until this point. The first argument after the application class name is the first **String** in the array **args**, and the length of the array is the total number of command-line arguments. Line 60 begins the definition of **main** and declares array **args** as an array of **String**s that allows the application to access the command-line arguments. Line 62 defines variables **width** and **height** that are used to specify the size of the application window.

```
1  // Fig. 13.9: DrawShapes\.java
2  // Draw random lines, rectangles and ovals
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class DrawShapes extends JApplet {
12    private JButton choices[];
13    private String names[] = { "Line", "Rectangle", "Oval" };
14    private JPanel buttonPanel;
15    private DrawPanel drawingPanel;
16    private int width = 300, height = 200;
17
18    // initialize applet; set up GUI
19    public void init()
20    {
21       // set up DrawPanel
22       drawingPanel = new DrawPanel( width, height );
23
24       // create array of buttons
25       choices = new JButton[ names.length ];
26
27       // set up panel for buttons
28       buttonPanel = new JPanel();
29       buttonPanel.setLayout(
30          new GridLayout( 1, choices.length ) );
31
32       // set up buttons and register their listeners
33       ButtonHandler handler = new ButtonHandler();
34
35       for ( int count = 0; count < choices.length; count++ ) {
36          choices[ count ] = new JButton( names[ count ] );
37          buttonPanel.add( choices[ count ] );
38          choices[ count ].addActionListener( handler );
39       }
```

Fig. 13.9 Creating a GUI-based application from an applet (part 1 of 4).

```
40
41          // attach components to content pane
42          Container container = getContentPane();
43          container.add( buttonPanel, BorderLayout.NORTH );
44          container.add( drawingPanel, BorderLayout.CENTER );
45       }
46
47       // enables application to specify width of drawing area
48       public void setWidth( int newWidth )
49       {
50          width = ( newWidth >= 0 ? newWidth : 300 );
51       }
52
53       // enables application to specify height of drawing area
54       public void setHeight( int newHeight )
55       {
56          height = ( newHeight >= 0 ? newHeight : 200 );
57       }
58
59       // execute applet as an application
60       public static void main( String args[] )
61       {
62          int width, height;
63
64          // check for command-line arguments
65          if ( args.length != 2 ) {
66             width = 300;
67             height = 200;
68          }
69          else {
70             width = Integer.parseInt( args[ 0 ] );
71             height = Integer.parseInt( args[ 1 ] );
72          }
73
74          // create window in which applet will execute
75          JFrame applicationWindow =
76             new JFrame( "An applet running as an application" );
77
78          applicationWindow.setDefaultCloseOperation(
79             JFrame.EXIT_ON_CLOSE );
80
81          // create one applet instance
82          DrawShapes appletObject = new DrawShapes();
83          appletObject.setWidth( width );
84          appletObject.setHeight( height );
85
86          // call applet's init and start methods
87          appletObject.init();
88          appletObject.start();
89
90          // attach applet to center of window
91          applicationWindow.getContentPane().add( appletObject );
92
```

Fig. 13.9 Creating a GUI-based application from an applet (part 2 of 4).

```
93          // set the window's size
94          applicationWindow.setSize( width, height );
95
96          // showing the window causes all GUI components
97          // attached to the window to be painted
98          applicationWindow.setVisible( true );
99       }
100
101      // private inner class to handle button events
102      private class ButtonHandler implements ActionListener {
103
104         // determine button user pressed and set drawing area's
105         // current choice
106         public void actionPerformed( ActionEvent event )
107         {
108            for ( int count = 0; count < choices.length; count++ )
109
110               if ( event.getSource() == choices[ count ] ) {
111                  drawingPanel.setCurrentChoice( count );
112                  break;
113               }
114         }
115
116      }  // end private inner class ButtonHandler
117
118   }  // end class DrawShapes
119
120   // subclass of JPanel to allow drawing in a separate area
121   class DrawPanel extends JPanel {
122      private int currentChoice = -1;  // don't draw first time
123      private int width = 100, height = 100;
124
125      // initialize width and height of DrawPanel
126      public DrawPanel( int newWidth, int newHeight )
127      {
128         width = ( newWidth >= 0 ? newWidth : 100 );
129         height = ( newHeight >= 0 ? newHeight : 100 );
130      }
131
132      // draw line, rectangle or oval based on user's choice
133      public void paintComponent( Graphics g )
134      {
135         super.paintComponent( g );
136
137         switch( currentChoice ) {
138
139            case 0:
140               g.drawLine( randomX(), randomY(),
141                  randomX(), randomY() );
142               break;
143
```

Fig. 13.9 Creating a GUI-based application from an applet (part 3 of 4).

```
144            case 1:
145               g.drawRect( randomX(), randomY(),
146                  randomX(), randomY() );
147               break;
148
149            case 2:
150               g.drawOval( randomX(), randomY(),
151                  randomX(), randomY() );
152               break;
153         }
154
155      }  // end method paintComponent
156
157      // specify current shape choice and repaint
158      public void setCurrentChoice( int choice )
159      {
160         currentChoice = choice;
161         repaint();
162      }
163
164      // pick random x coordinate
165      private int randomX()
166      {
167         return ( int ) ( Math.random() * width );
168      }
169
170      // pick random y coordinate
171      private int randomY()
172      {
173         return ( int ) ( Math.random() * height );
174      }
175
176   }  // end class DrawPanel
```

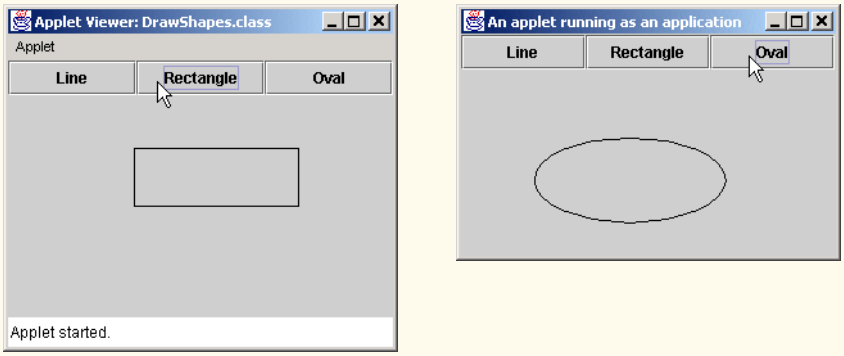


Fig. 13.9 Creating a GUI-based application from an applet (part 4 of 4).

Lines 65–72 determine the initial width and height of the application window. The **`if`** condition determines the length of array **`args`**. If the number of elements is not 2, the **`width`** and **`height`** are set to 300 and 200 by default. Otherwise, lines 70–71 convert the command-line arguments from **`String`**s to **`int`** values with **`parseInt`** and use them as the **`width`**

and **height**. [*Note*: This program assumes that the user inputs whole-number values for the command-line arguments; if not, an exception will occur. In Chapter 14, we discuss how to make our programs more robust by dealing with improper values when they occur.]

When an applet executes, the window in which it executes is supplied by the applet container (i.e., the **appletviewer** or browser). When a program executes as an application, the application must create its own window (if one is required). Lines 75–76 create the **JFrame** to which the program will attach the applet. As with any **JFrame** that is used as the application's primary window, you should provide a mechanism to terminate the application. Lines 78–79 specify that the application should terminate when the user closes the window.

Software Engineering Observation 13.3

To execute an applet as an application, the application must provide a window in which the applet can be displayed.

When an applet executes in an applet container, the container creates one object of the applet class to execute the applet's tasks. In an application, objects are not created unless the application explicitly contains statements that create objects. Line 82 defines one instance of applet class **DrawShapes**. Notice the call to the no-argument constructor. We did not define a constructor in class **DrawShapes** (applet classes typically do not define constructors). Remember that the compiler provides a default constructor for a class that does not define any constructors. Lines 83–84 call **DrawShapes** methods **setWidth** and **setHeight** to validate the values for **width** and **height** (improper values are set to 300 and 200, respectively).

Software Engineering Observation 13.4

To execute an applet as an application, the application must create an instance of the applet class to execute.

When an applet executes in an applet container, the container guarantees that methods **init**, **start** and **paint** will be called to begin the applet's execution. However, these methods are not special to an application. Method **init** and **start** are not invoked automatically or required by an application. (Method paint is part of any window and will be called when it is necessary to repaint the window.) Lines 87–88 invoke **appletObject**'s **init** method to initialize the applet and set up its GUI, then invoke method **start**. [*Note*: In our example, we did not override method **start**. It is called here to mimic the start-up sequence normally followed for an applet.]

Software Engineering Observation 13.5

*When executing an applet as an application, the application must call **init** and **start** explicitly to simulate the normal applet start-up sequence of method calls.*

When an applet executes in an applet container, the applet is normally attached to the applet container's window. An application must explicitly attach an applet object to the application window. Line 91 obtains a reference to the **applicationWindow**'s content pane and adds the **appletObject** to the default **CENTER** of the content pane's **BorderLayout**. The **appletObject** will occupy the entire window.

Software Engineering Observation 13.6

When one is executing an applet as an application, the application must attach the applet object to its window.

Finally, the application window must be sized and displayed on the screen. Line 94 sets the application window's size, and line 98 displays the window. When a Java program displays any window, all the components attached to the window receive calls to their **`paint`** methods (if they are heavyweight components) or their **`paintComponent`** methods (if they are lightweight components). Thus, displaying the application window results in a call to the applet's **`paint`** method to complete the normal start-up sequence for the applet.

Try executing this program as an applet and as an application to see that it has the same functionality when executed.

13.8 Using Menus with Frames

Menus are an integral part of GUIs. Menus allow the user to perform actions without unnecessarily "cluttering" a graphical user interface with extra GUI components. In Swing GUIs, menus can be attached only to objects of the classes that provide method **`setJMenuBar`**. Two such classes are **`JFrame`** and **`JApplet`**. The classes used to define menus are ***`JMenuBar`***, ***`JMenuItem`***, ***`JMenu`***, ***`JCheckBoxMenuItem`*** and class ***`JRadioButtonMenuItem`***.

Look-and-Feel Observation 13.16

Menus simplify GUIs by reducing the number of components the user views.

Class **`JMenuBar`** (a subclass of **`JComponent`**) contains the methods necessary to manage a *menu bar*, which is a container for menus.

Class **`JMenuItem`** (a subclass of **`javax.swing.AbstractButton`**) contains the methods necessary to manage *menu items*. A menu item is a GUI component inside a menu that, when selected, causes an action to be performed. A menu item can be used to initiate an action or it can be a *submenu* that provides more menu items from which the user can select. Submenus are useful for grouping related menu items in a menu.

Class **`JMenu`** (a subclass of **`javax.swing.JMenuItem`**) contains the methods necessary for managing *menus*. Menus contain menu items and are added to menu bars or to other menus as submenus. When a menu is clicked, the menu expands to show its list of menu items. Clicking a menu item generates an action event.

Class **`JCheckBoxMenuItem`** (a subclass of **`javax.swing.JMenuItem`**) contains the methods necessary to manage menu items that can be toggled on or off. When a **`JCheckBoxMenuItem`** is selected, a check appears to the left of the menu item. When the **`JCheckBoxMenuItem`** is selected again, the check to the left of the menu item is removed.

Class **`JRadioButtonMenuItem`** (a subclass of **`javax.swing.JMenuItem`**) contains the methods necessary to manage menu items that can be toggled on or off like **`JCheckBoxMenuItem`**s. When multiple **`JRadioButtonMenuItem`**s are maintained as part of a **`ButtonGroup`**, only one item in the group can be selected at a given time. When a **`JRadioButtonMenuItem`** is selected, a filled circle appears to the left of the menu item. When another **`JRadioButtonMenuItem`** is selected, the filled circle to the left of the previously selected menu item is removed.

The application of Fig. 13.10 demonstrates various types of menu items. The program also demonstrates how to specify special characters called mnemonics that can provide quick access to a menu or menu item from the keyboard. Mnemonics can be used with objects of all classes that have subclass **`javax.swing.AbstractButton`**.

```
1  // Fig. 13.10: MenuTest.java
2  // Demonstrating menus
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class MenuTest extends JFrame {
12    private Color colorValues[] =
13       { Color.black, Color.blue, Color.red, Color.green };
14
15    private JRadioButtonMenuItem colorItems[], fonts[];
16    private JCheckBoxMenuItem styleItems[];
17    private JLabel displayLabel;
18    private ButtonGroup fontGroup, colorGroup;
19    private int style;
20
21    // set up GUI
22    public MenuTest()
23    {
24       super( "Using JMenus" );
25
26       // set up File menu and its menu items
27       JMenu fileMenu = new JMenu( "File" );
28       fileMenu.setMnemonic( 'F' );
29
30       // set up About... menu item
31       JMenuItem aboutItem = new JMenuItem( "About..." );
32       aboutItem.setMnemonic( 'A' );
33
34       aboutItem.addActionListener(
35
36          // anonymous inner class to handle menu item event
37          new ActionListener() {
38
39             // display message dialog when user selects About...
40             public void actionPerformed( ActionEvent event )
41             {
42                JOptionPane.showMessageDialog( MenuTest.this,
43                   "This is an example\nof using menus",
44                   "About", JOptionPane.PLAIN_MESSAGE );
45             }
46
47          }  // end anonymous inner class
48
49       ); // end call to addActionListener
50
51       fileMenu.add( aboutItem );
52
```

Fig. 13.10 Using **JMenu**s and mnemonics (part 1 of 5).

```
53          // set up Exit menu item
54          JMenuItem exitItem = new JMenuItem( "Exit" );
55          exitItem.setMnemonic( 'x' );
56
57          exitItem.addActionListener(
58
59             // anonymous inner class to handle exitItem event
60             new ActionListener() {
61
62                // terminate application when user clicks exitItem
63                public void actionPerformed( ActionEvent event )
64                {
65                   System.exit( 0 );
66                }
67
68             }  // end anonymous inner class
69
70          ); // end call to addActionListener
71
72          fileMenu.add( exitItem );
73
74          // create menu bar and attach it to MenuTest window
75          JMenuBar bar = new JMenuBar();
76          setJMenuBar( bar );
77          bar.add( fileMenu );
78
79          // create Format menu, its submenus and menu items
80          JMenu formatMenu = new JMenu( "Format" );
81          formatMenu.setMnemonic( 'r' );
82
83          // create Color submenu
84          String colors[] = { "Black", "Blue", "Red", "Green" };
85
86          JMenu colorMenu = new JMenu( "Color" );
87          colorMenu.setMnemonic( 'C' );
88
89          colorItems = new JRadioButtonMenuItem[ colors.length ];
90          colorGroup = new ButtonGroup();
91          ItemHandler itemHandler = new ItemHandler();
92
93          // create color radio button menu items
94          for ( int count = 0; count < colors.length; count++ ) {
95             colorItems[ count ] =
96                new JRadioButtonMenuItem( colors[ count ] );
97
98             colorMenu.add( colorItems[ count ] );
99             colorGroup.add( colorItems[ count ] );
100
101            colorItems[ count ].addActionListener( itemHandler );
102         }
103
104         // select first Color menu item
105         colorItems[ 0 ].setSelected( true );
```

Fig. 13.10 Using **JMenu**s and mnemonics (part 2 of 5).

```
106
107         // add format menu to menu bar
108         formatMenu.add( colorMenu );
109         formatMenu.addSeparator();
110
111         // create Font submenu
112         String fontNames[] = { "Serif", "Monospaced", "SansSerif" };
113
114         JMenu fontMenu = new JMenu( "Font" );
115         fontMenu.setMnemonic( 'n' );
116
117         fonts = new JRadioButtonMenuItem[ fontNames.length ];
118         fontGroup = new ButtonGroup();
119
120         // create Font radio button menu items
121         for ( int count = 0; count < fonts.length; count++ ) {
122            fonts[ count ] =
123               new JRadioButtonMenuItem( fontNames[ count ] );
124
125            fontMenu.add( fonts[ count ] );
126            fontGroup.add( fonts[ count ] );
127
128            fonts[ count ].addActionListener( itemHandler );
129         }
130
131         // select first Font menu item
132         fonts[ 0 ].setSelected( true );
133
134         fontMenu.addSeparator();
135
136         // set up style menu items
137         String styleNames[] = { "Bold", "Italic" };
138
139         styleItems = new JCheckBoxMenuItem[ styleNames.length ];
140         StyleHandler styleHandler = new StyleHandler();
141
142         // create style checkbox menu items
143         for ( int count = 0; count < styleNames.length; count++ ) {
144            styleItems[ count ] =
145               new JCheckBoxMenuItem( styleNames[ count ] );
146
147            fontMenu.add( styleItems[ count ] );
148
149            styleItems[ count ].addItemListener( styleHandler );
150         }
151
152         // put Font menu in Format menu
153         formatMenu.add( fontMenu );
154
155         // add Format menu to menu bar
156         bar.add( formatMenu );
157
```

Fig. 13.10 Using **JMenu**s and mnemonics (part 3 of 5).

```
158         // set up label to display text
159         displayLabel = new JLabel(
160            "Sample Text", SwingConstants.CENTER );
161         displayLabel.setForeground( colorValues[ 0 ] );
162         displayLabel.setFont(
163            new Font( "TimesRoman", Font.PLAIN, 72 ) );
164
165         getContentPane().setBackground( Color.cyan );
166         getContentPane().add( displayLabel, BorderLayout.CENTER );
167
168         setSize( 500, 200 );
169         setVisible( true );
170
171      }  // end constructor
172
173      // execute application
174      public static void main( String args[] )
175      {
176         MenuTest application = new MenuTest();
177
178         application.setDefaultCloseOperation(
179            JFrame.EXIT_ON_CLOSE );
180      }
181
182      // inner class to handle action events from menu items
183      private class ItemHandler implements ActionListener {
184
185         // process color and font selections
186         public void actionPerformed( ActionEvent event )
187         {
188            // process color selection
189            for ( int count = 0; count < colorItems.length; count++ )
190
191               if ( colorItems[ count ].isSelected() ) {
192                  displayLabel.setForeground( colorValues[ count ] );
193                  break;
194               }
195
196            // process font selection
197            for ( int count = 0; count < fonts.length; count++ )
198
199               if ( event.getSource() == fonts[ count ] ) {
200                  displayLabel.setFont( new Font(
201                     fonts[ count ].getText(), style, 72 ) );
202                  break;
203               }
204
205            repaint();
206         }
207
208      }  // end class ItemHandler
209
```

Fig. 13.10 Using **JMenu**s and mnemonics (part 4 of 5).

```
210    // inner class to handle item events from check box menu items
211    private class StyleHandler implements ItemListener {
212
213       // process font style selections
214       public void itemStateChanged( ItemEvent e )
215       {
216          style = 0;
217
218          // check for bold selection
219          if ( styleItems[ 0 ].isSelected() )
220             style += Font.BOLD;
221
222          // check for italic selection
223          if ( styleItems[ 1 ].isSelected() )
224             style += Font.ITALIC;
225
226          displayLabel.setFont( new Font(
227             displayLabel.getFont().getName(), style, 72 ) );
228
229          repaint();
230       }
231
232    }  // end class StyleHandler
233
234 }  // end class MenuTest
```

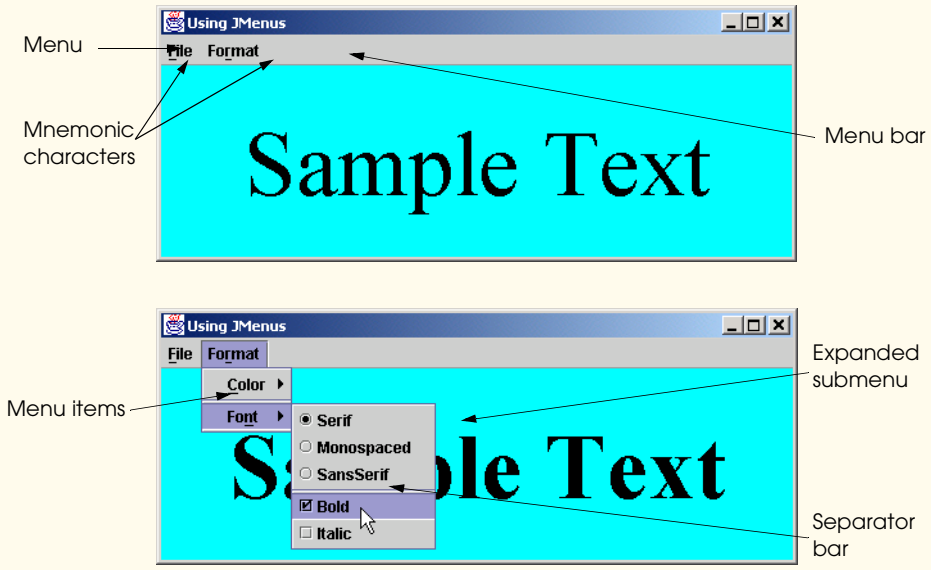


Fig. 13.10 Using **JMenu**s and mnemonics (part 5 of 5).

Class **MenuTest** (line 11) is a completely self-contained class—it defines all the GUI components and event handling for the menu items. Most of the code for this application appears in the class's constructor (lines 22–171).

Lines 27–72 set up the **File** menu and attach it to the menu bar. The **File** menu contains an **About...** menu item that displays a message dialog when the menu item is selected and an **Exit** menu item that can be selected to terminate the application.

Line 27 creates **`fileMenu`** and passes to the constructor the string "**`File`**" as the name of the menu. Line 28 uses **`AbstractButton`** method ***`setMnemonic`*** (inherited into class **`JMenu`**) to indicate that **`F`** is the *mnemonic* for this menu. Pressing the *Alt* key and the letter *F* opens the menu, just as clicking the menu name with the mouse would. In the GUI, the mnemonic character in the menu's name is displayed with an underline (see the screen captures).

Look-and-Feel Observation 13.17

Mnemonics provide quick access to menu commands and button commands through the keyboard.

Look-and-Feel Observation 13.18

Different mnemonics should be used for each button or menu item. Normally, the first letter in the label on the menu item or button is used as the mnemonic. If multiple buttons or menu items start with the same letter, choose the next most prominent letter in the name (e.g., ***`x`*** *is commonly chosen for a button or menu item called* ***Exit****).*

Lines 31–32 define **`JMenuItem`** **`aboutItem`** with the name "**`About...`**" and set its mnemonic to the letter **`A`**. This menu item is added to **`fileMenu`** at line 51. To access the **About...** item through the keyboard, press the *Alt* key and letter *F* to open the **File** menu, then press *A* to select the **About...** menu item. Lines 34–49 create an **`ActionListener`** to process **`aboutItem`**'s action event. Lines 42–44 display a message dialog box. In most prior uses of **`showMessageDialog`**, the first argument has been **`null`**. The purpose of the first argument is to specify the *parent window* for the dialog box. The parent window helps determine where the dialog box will be displayed. If the parent window is specified as **`null`**, the dialog box appears in the center of the screen. If the parent window is not **`null`**, the dialog box appears centered over the specified parent window. In this example, the program specifies the parent window with **`MenuTest.this`**—the **`this`** reference of class **`MenuTest`**. When using the **`this`** reference in an inner class, specifying **`this`** by itself refers to the inner-class object. To reference the outer-class object's **`this`** reference, qualify **`this`** with the outer-class name and a dot operator (**`.`**).

Dialog boxes can be either *modal* or *modeless*. A *modal dialog box* does not allow any other window in the application to be accessed until the dialog box is dismissed. A *modeless dialog box* allows other windows to be accessed while the dialog is displayed. By default, the dialogs displayed with class **`JOptionPane`** are modal dialogs. Class ***`JDialog`*** can be used to create your own modeless or modal dialogs.

Lines 54–72 define menu item **`exitItem`**, set its mnemonic to **`x`**, register an **`ActionListener`** that terminates the application when the user selects **`exitItem`** and add **`exitItem`** to the **`fileMenu`**.

Lines 75–77 create the **`JMenuBar`**, attach it to the application window with **`JFrame`** method ***`setJMenuBar`*** and use **`JMenuBar`** method ***`add`*** to attach the **`fileMenu`** to the menu bar.

Common Programming Error 13.5

Forgetting to set the menu bar with ***`JFrame`*** *method* ***`setJMenuBar`*** *results in the menu bar not being displayed on the* ***`JFrame`****.*

Look-and-Feel Observation 13.19

Menus normally appear left to right in the order that they are added to a ***JMenuBar****.*

Lines 80–81 create menu **formatMenu** and set its mnemonic to **r** (**F** is not used because that is the **File** menu's mnemonic).

Lines 86–87 create menu **colorMenu** (this will be a submenu in the **Format** menu) and set its mnemonic to **C**. Line 89 creates **JRadioButtonMenuItem** array **colorItems** that refers to the menu items in **colorMenu**. Line 90 creates the **ButtonGroup colorGroup**, which ensures that only one of the menu items in the **Color** submenu is selected at a time. Line 91 defines an instance of inner class **ItemHandler** (defined at lines 183–208) that responds to selections from the **Color** submenu and the **Font** submenu (discussed shortly). The **for** structure at lines 94–102 creates each **JRadioButtonMenuItem** in array **colorItems**, adds each menu item to **colorMenu**, adds each menu item to **colorGroup** and registers the **ActionListener** for each menu item.

Line 105 uses **AbstractButton** method ***setSelected*** to select the first element in the **colorItems** array. Line 108 adds the **colorMenu** as a submenu of the **formatMenu**.

Look-and-Feel Observation 13.20

Adding a menu as a menu item in another menu automatically makes the added menu a submenu. When the mouse is positioned over a submenu (or the submenu's mnemonic is pressed), the submenu expands to show its menu items.

Line 109 adds a *separator* line to the menu. The separator appears as a horizontal line in the menu.

Look-and-Feel Observation 13.21

Separators can be added to a menu to group menu items logically.

Look-and-Feel Observation 13.22

Any lightweight GUI component (i.e., a component that subclasses ***JComponent****) can be added to a* ***JMenu*** *or to a* ***JMenuBar****.*

Lines 114–132 create the **Font** submenu and several **JRadioButtonMenuItem**s and select the first element of **JRadioButtonMenuItem** array **fonts**. Line 139 creates a **JCheckBoxMenuItem** array to represent the menu items for specifying bold and italic styles for the fonts. Line 140 defines an instance of inner class **StyleHandler** (defined at lines 211–232) to respond to the **JCheckBoxMenuItem** events. The **for** structure at lines 143–150 creates each **JCheckBoxMenuItem**, adds each menu item to **fontMenu** and registers the **ItemListener** for each menu item. Line 153 adds **fontMenu** as a submenu of **formatMenu**. Line 156 adds the **formatMenu** to **bar**.

Lines 159–163 create a **JLabel** for which the **Format** menu items control the font, font color and font style. The initial foreground color is set to the first element of array **colorValues** (**Color.black**) and the initial font is set to **TimesRoman** with **PLAIN** style and **72**-point size. Line 165 sets the background color of the window's content pane to **Color.cyan**, and line 166 attaches the **JLabel** to the **CENTER** of the content pane's **BorderLayout**.

Method **actionPerformed** of class **ItemHandler** (lines 186–206) uses two **for** structures to determine which font or color menu item generated the event and sets the font or color of the **JLabel display**, respectively. The **if** condition at line 191 uses **AbstractButton** method ***isSelected*** to determine the selected **JRadioButtonMenuItem**. The **if** condition at line 199 uses **EventSource** method **getSource** to get a reference to the **JRadioButtonMenuItem** that generated the event. Line 201 uses **AbstractButton** method **getText** to obtain the name of the font from the menu item.

The program calls method **itemStateChanged** of class **StyleHandler** (lines 214–230) if the user selects a **JCheckBoxMenuItem** in the **fontMenu**. Lines 219 and 223 determine whether either or both of the **JCheckBoxMenuItem**s are selected and use their combined state to determine the new style of the font.

13.9 Using JPopupMenus

Many of today's computer applications provide so-called *context-sensitive popup menus*. In Swing, such menus are created with class **JPopupMenu** (a subclass of **JComponent**). These menus provide options that are specific to the component for which the *popup trigger event* was generated. On most systems, the popup trigger event occurs when the user presses and releases the right mouse button.

Look-and-Feel Observation 13.23

The popup trigger event is platform specific. On most platforms that use a mouse with multiple mouse buttons, the popup trigger event occurs when the user clicks the right mouse button.

Figure 13.11 creates a **JPopupMenu** that allows the user to select one of three colors and change the background color of the window. When the user clicks the right mouse button on the **PopupTest** window's background, a **JPopupMenu** containing colors appears. If the user clicks one of the **JRadioButtonMenuItem**s that represents a color, method **actionPerformed** of class **ItemHandler** changes the background color of the window's content pane.

```
1  // Fig. 13.11: PopupTest.java
2  // Demonstrating JPopupMenus
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class PopupTest extends JFrame {
12
13    private JRadioButtonMenuItem items[];
14    private Color colorValues[] =
15       { Color.blue, Color.yellow, Color.red };
16
17    private JPopupMenu popupMenu;
18
```

Fig. 13.11 Using a **PopupMenu** object (part 1 of 3).

```
19       // set up GUI
20       public PopupTest()
21       {
22          super( "Using JPopupMenus" );
23
24          ItemHandler handler = new ItemHandler();
25          String colors[] = { "Blue", "Yellow", "Red" };
26
27          // set up popup menu and its items
28          ButtonGroup colorGroup = new ButtonGroup();
29          popupMenu = new JPopupMenu();
30          items = new JRadioButtonMenuItem[ 3 ];
31
32          // construct each menu item and add to popup menu; also
33          // enable event handling for each menu item
34          for ( int count = 0; count < items.length; count++ ) {
35             items[ count ] =
36                new JRadioButtonMenuItem( colors[ count ] );
37
38             popupMenu.add( items[ count ] );
39             colorGroup.add( items[ count ] );
40
41             items[ count ].addActionListener( handler );
42          }
43
44          getContentPane().setBackground( Color.white );
45
46          // define a MouseListener for the window that displays
47          // a JPopupMenu when the popup trigger event occurs
48          addMouseListener(
49
50             // anonymous inner class to handle mouse events
51             new MouseAdapter() {
52
53                // handle mouse press event
54                public void mousePressed( MouseEvent event )
55                {
56                   checkForTriggerEvent( event );
57                }
58
59                // handle mouse release event
60                public void mouseReleased( MouseEvent event )
61                {
62                   checkForTriggerEvent( event );
63                }
64
65                // determine whether event should trigger popup menu
66                private void checkForTriggerEvent( MouseEvent event )
67                {
68                   if ( event.isPopupTrigger() )
69                      popupMenu.show( event.getComponent(),
70                         event.getX(), event.getY() );
71                }
```

Fig. 13.11 Using a **PopupMenu** object (part 2 of 3).

```
72
73             }  // end anonymous inner clas
74
75          ); // end call to addMouseListener
76
77          setSize( 300, 200 );
78          setVisible( true );
79       }
80
81       // execute application
82       public static void main( String args[] )
83       {
84          PopupTest application = new PopupTest();
85
86          application.setDefaultCloseOperation(
87             JFrame.EXIT_ON_CLOSE );
88       }
89
90       // private inner class to handle menu item events
91       private class ItemHandler implements ActionListener {
92
93          // process menu item selections
94          public void actionPerformed( ActionEvent event )
95          {
96             // determine which menu item was selected
97             for ( int i = 0; i < items.length; i++ )
98                if ( event.getSource() == items[ i ] ) {
99                   getContentPane().setBackground(
100                     colorValues[ i ] );
101                  repaint();
102                  return;
103               }
104         }
105
106      }  // end private inner class ItemHandler
107
108   }  // end class PopupTest
```

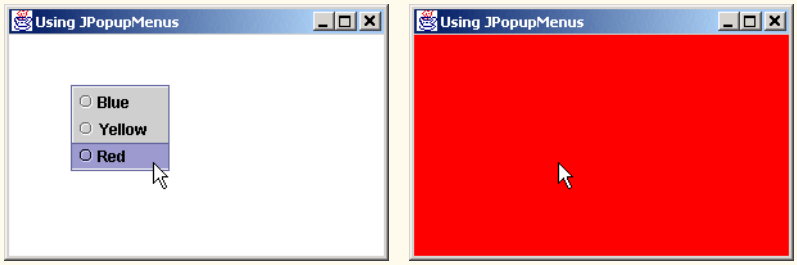


Fig. 13.11 Using a **PopupMenu** object (part 3 of 3).

The constructor for class **PopupTest** (lines 20–79) defines the **JPopupMenu** at line 29. The **for** structure at lines 34–42 creates **JRadioButtonMenuItem**s to add to the **JPopupMenu**, adds them to the **JPopupMenu** (line 38), adds them to **ButtonGroup**

colorGroup (to maintain one selected **JRadioButtonMenuItem** at a time) and registers an **ActionListener** for each menu item.

Lines 48–75 register an instance of an anonymous inner class that extends **MouseAdapter** to handle the mouse events of the application window. Methods **mousePressed** (lines 54–57) and **mouseReleased** (lines 60–63) check for the popup-trigger event. Each method calls **private** utility method **checkForTriggerEvent** (lines 66–71) to determine whether the popup-trigger event occurred. **MouseEvent** method ***isPopupTrigger*** returns **true** if the popup-trigger event occurred. If so, method ***show*** of class **JPopupMenu** displays the **JPopupMenu**. The first argument to method **show** specifies the *origin component,* whose position helps determine where the **JPopupMenu** will appear on the screen. The last two arguments are the *x*-*y* coordinate from the origin component's upper-left corner at which the **JPopupMenu** should appear.

Look-and-Feel Observation 13.24

*Displaying a **JPopupMenu** for the popup-trigger event of multiple different GUI components requires registering mouse event handlers to check for the popup-trigger event for each of those GUI components.*

When the user selects a menu item from the popup menu, class **ItemHandler**'s (lines 91–106) method **actionPerformed** (lines 94–104) determines which **JRadioButtonMenuItem** the user selected, then sets the background color of the window's content pane.

13.10 Pluggable Look-and-Feel

A program that uses Java's Abstract Windowing Toolkit GUI components (package ***java.awt***) takes on the look-and-feel of the platform on which the program executes. A Java program running on a Macintosh looks like other programs running on a Macintosh. A Java program running on Microsoft Windows looks like other programs running on Microsoft Windows. A Java program running on a UNIX platform looks like other programs running on that UNIX platform. This could be desirable, because it allows users of the program on each platform to use the GUI components with which they are already familiar. However, this also introduces interesting portability issues.

Portability Tip 13.1

*Programs that use Java's Abstract Windowing Toolkit GUI components (package **java.awt**) take on the look-and-feel of the platform on which they execute.*

Portability Tip 13.2

GUI components on each platform have different looks that can require different amounts of space to display. This could change the layout and alignments of GUI components.

Portability Tip 13.3

GUI components on each platform have different default functionality (e.g., some platforms allow a button with the focus to be "pressed" with the space bar, and some do not).

Swing's lightweight GUI components eliminate many of these issues by providing uniform functionality across platforms and by defining a uniform cross-platform look-and-feel (known as the metal look-and-feel). Swing also provides the flexibility to customize

the look-and-feel to appear as a Microsoft Windows-style look-and-feel or a Motif-style (UNIX) look-and-feel.

The program of Fig. 13.12 demonstrates how to change the look-and-feel of a Swing GUI. The program creates several GUI components so you can see the change in the look-and-feel of several GUI components at the same time. The first output window shows the standard metal look-and-feel, the second output window shows the Motif look-and-feel, and the third output window shows the Windows look-and-feel.

```
1  // Fig. 13.12: LookAndFeelDemo.java
2  // Changing the look and feel.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class LookAndFeelDemo extends JFrame {
12
13    private String strings[] = { "Metal", "Motif", "Windows" };
14    private UIManager.LookAndFeelInfo looks[];
15    private JRadioButton radio[];
16    private ButtonGroup group;
17    private JButton button;
18    private JLabel label;
19    private JComboBox comboBox;
20
21    // set up GUI
22    public LookAndFeelDemo()
23    {
24       super( "Look and Feel Demo" );
25
26       Container container = getContentPane();
27
28       // set up panel for NORTH of BorderLayout
29       JPanel northPanel = new JPanel();
30       northPanel.setLayout( new GridLayout( 3, 1, 0, 5 ) );
31
32       // set up label for NORTH panel
33       label = new JLabel( "This is a Metal look-and-feel",
34          SwingConstants.CENTER );
35       northPanel.add( label );
36
37       // set up button for NORTH panel
38       button = new JButton( "JButton" );
39       northPanel.add( button );
40
41       // set up combo box for NORTH panel
42       comboBox = new JComboBox( strings );
43       northPanel.add( comboBox );
```

Fig. 13.12 Changing the look-and-feel of a Swing-based GUI (part 1 of 3).

```
44
45          // attach NORTH panel to content pane
46          container.add( northPanel, BorderLayout.NORTH );
47
48          // create array for radio buttons
49          radio = new JRadioButton[ strings.length ];
50
51          // set up panel for SOUTH of BorderLayout
52          JPanel southPanel = new JPanel();
53          southPanel.setLayout(
54             new GridLayout( 1, radio.length ) );
55
56          // set up radio buttons for SOUTH panel
57          group = new ButtonGroup();
58          ItemHandler handler = new ItemHandler();
59
60          for ( int count = 0; count < radio.length; count++ ) {
61             radio[ count ] = new JRadioButton( strings[ count ] );
62             radio[ count ].addItemListener( handler );
63             group.add( radio[ count ] );
64             southPanel.add( radio[ count ] );
65          }
66
67          // attach SOUTH panel to content pane
68          container.add( southPanel, BorderLayout.SOUTH );
69
70          // get installed look-and-feel information
71          looks = UIManager.getInstalledLookAndFeels();
72
73          setSize( 300, 200 );
74          setVisible( true );
75
76          radio[ 0 ].setSelected( true );
77       }
78
79       // use UIManager to change look-and-feel of GUI
80       private void changeTheLookAndFeel( int value )
81       {
82          // change look and feel
83          try {
84             UIManager.setLookAndFeel(
85                looks[ value ].getClassName() );
86             SwingUtilities.updateComponentTreeUI( this );
87          }
88
89          // process problems changing look and feel
90          catch ( Exception exception ) {
91             exception.printStackTrace();
92          }
93       }
94
```

Fig. 13.12 Changing the look-and-feel of a Swing-based GUI (part 2 of 3).

```
95      // execute application
96      public static void main( String args[] )
97      {
98         LookAndFeelDemo application = new LookAndFeelDemo();
99
100        application.setDefaultCloseOperation(
101           JFrame.EXIT_ON_CLOSE );
102     }
103
104     // private inner class to handle radio button events
105     private class ItemHandler implements ItemListener {
106
107        // process user's look-and-feel selection
108        public void itemStateChanged( ItemEvent event )
109        {
110           for ( int count = 0; count < radio.length; count++ )
111
112              if ( radio[ count ].isSelected() ) {
113                 label.setText( "This is a " +
114                    strings[ count ] + " look-and-feel" );
115                 comboBox.setSelectedIndex( count );
116
117                 changeTheLookAndFeel( count );
118              }
119        }
120
121     }  // end private inner class ItemHandler
122
123  }  // end class LookAndFeelDemo
```

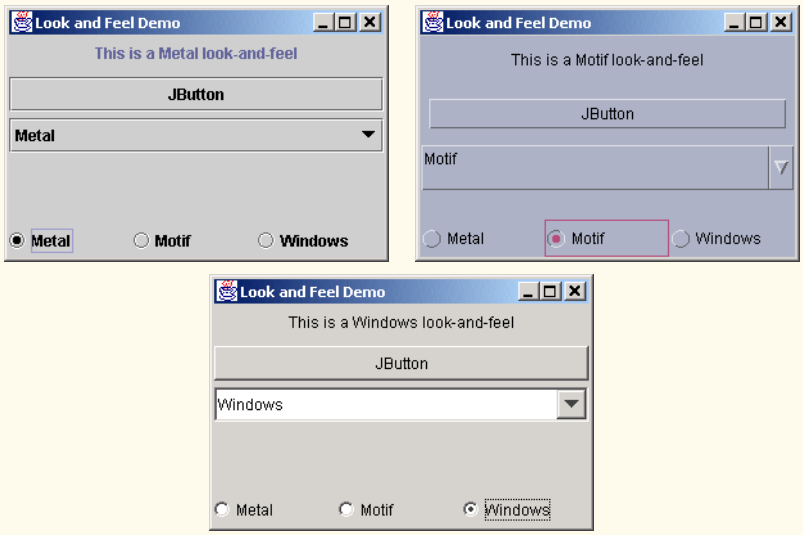


Fig. 13.12 Changing the look-and-feel of a Swing-based GUI (part 3 of 3).

All the GUI components and event handling in this example have been covered before, so we concentrate on the mechanism for changing the look-and-feel in this example.

Class ***UIManager*** (package ***javax.swing***) contains **public static** inner class ***LookAndFeelInfo*** that is used to maintain information about a look-and-feel. Line 14 declares an array of type **UIManager.LookAndFeelInfo** (notice the syntax used to access the inner class **LookAndFeelInfo**). Line 71 uses **static** method ***getInstalledLookAndFeels*** of class **UIManager** to get the array of **UIManager.LookAndFeelInfo** objects that describe the installed look-and-feels.

Performance Tip 13.1

Each look-and-feel is represented by a Java class. ***UIManager*** *method* ***getInstalledLookAndFeels*** *does not load each class. Rather, it provides access to the names of each look-and-feel, so a choice of look-and-feel can be made (presumably one time at program start-up). This reduces the overhead of loading additional classes that the program will not use.*

Utility method **changeTheLookAndFeel** (lines 80–93) is called by the event handler (defined in **private** inner class **ItemHandler** at lines 105–121) for the **JRadioButton**s at the bottom of the user interface. The event handler passes an integer representing the element in array **looks** that should be used to change the look-and-feel. Lines 84–85 use **static** method ***setLookAndFeel*** of class **UIManager** to change the look-and-feel. Method ***getClassName*** of class **UIManager.LookAndFeelInfo** determines the name of the look-and-feel class that corresponds to the **UIManager.LookAndFeelInfo**. If the look-and-feel class is not already loaded, it will be loaded as part of the call to **setLookAndFeel**. Line 86 uses **static** method ***updateComponentTreeUI*** of class ***SwingUtilities*** (package **javax.swing**) to change the look-and-feel of every component attached to its argument (this instance of class **LookAndFeelDemo**) to the new look-and-feel.

The preceding two statements appear in a special block of code called a ***try*** *block*. This code is part of the *exception-handling mechanism* discussed in detail in the next chapter. This code is required in case lines 84–85 attempt to change the look-and-feel to a look-and-feel that does not exist. Lines 90–92 complete the exception-handling mechanism with a ***catch*** *handler* that simply processes this problem (if it occurs) by printing an error message at the command line.

13.11 Using JDesktopPane and JInternalFrame

Many of today's applications use a *multiple document interface (MDI)* [i.e., a main window (often called the *parent window*) containing other windows (often called *child windows*)] to manage several open *documents* that are being processed in parallel. For example, many e-mail programs allow you to have several e-mail windows open at the same time so you can compose and/or read multiple e-mail messages. Similarly, many word processors allow the user to open multiple documents in separate windows so the user can switch between the documents without having to close the current document to open another document. The program of Fig. 13.13 demonstrates Swing's ***JDesktopPane*** and ***JInternalFrame*** classes, which provide support for creating multiple document interfaces. The child windows simply display an image of the cover of this book.

Lines 20–27 define a **JMenuBar**, a **JMenu** and a **JMenuItem**, add the **JMenuItem** to the **JMenu**, add the **JMenu** to the **JMenuBar** and set the **JMenuBar** for the application window. When the user selects the **JMenuItem newFrame**, the program creates and displays a new **JInternalFrame**.

```
1  // Fig. 13.13: DesktopTest.java
2  // Demonstrating JDesktopPane.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class DesktopTest extends JFrame {
12    private JDesktopPane theDesktop;
13
14    // set up GUI
15    public DesktopTest()
16    {
17       super( "Using a JDesktopPane" );
18
19       // create menu bar, menu and menu item
20       JMenuBar bar = new JMenuBar();
21       JMenu addMenu = new JMenu( "Add" );
22       JMenuItem newFrame = new JMenuItem( "Internal Frame" );
23
24       addMenu.add( newFrame );
25       bar.add( addMenu );
26
27       setJMenuBar( bar );
28
29       // set up desktop
30       theDesktop = new JDesktopPane();
31       getContentPane().add( theDesktop );
32
33       // set up listener for newFrame menu item
34       newFrame.addActionListener(
35
36          // anonymous inner class to handle menu item event
37          new ActionListener() {
38
39             // display new internal window
40             public void actionPerformed( ActionEvent event ) {
41
42                // create internal frame
43                JInternalFrame frame = new JInternalFrame(
44                   "Internal Frame", true, true, true, true );
45
46                // attach panel to internal frame content pane
47                Container container = frame.getContentPane();
48                MyJPanel panel = new MyJPanel();
49                container.add( panel, BorderLayout.CENTER );
50
51                // set size internal frame to size of its contents
52                frame.pack();
53
```

Fig. 13.13 Creating a multiple document interface (part 1 of 3).

```
54                // attach internal frame to desktop and show it
55                theDesktop.add( frame );
56                frame.setVisible( true );
57             }
58
59          }  // end anonymous inner class
60
61       ); // end call to addActionListener
62
63       setSize( 600, 440 );
64       setVisible( true );
65
66    }  // end constructor
67
68    // execute application
69    public static void main( String args[] )
70    {
71       DesktopTest application = new DesktopTest();
72
73       application.setDefaultCloseOperation(
74          JFrame.EXIT_ON_CLOSE );
75    }
76
77 }  // end class DesktopTest
78
79 // class to display an ImageIcon on a panel
80 class MyJPanel extends JPanel {
81    private ImageIcon imageIcon;
82
83    // load image
84    public MyJPanel()
85    {
86       imageIcon = new ImageIcon( "jhtp4.png" );
87    }
88
89    // display imageIcon on panel
90    public void paintComponent( Graphics g )
91    {
92       // call superclass paintComponent method
93       super.paintComponent( g );
94
95       // display icon
96       imageIcon.paintIcon( this, g, 0, 0 );
97    }
98
99    // return image dimensions
100   public Dimension getPreferredSize()
101   {
102      return new Dimension( imageIcon.getIconWidth(),
103         imageIcon.getIconHeight() );
104   }
105
106 }  // end class MyJPanel
```

Fig. 13.13 Creating a multiple document interface (part 2 of 3).

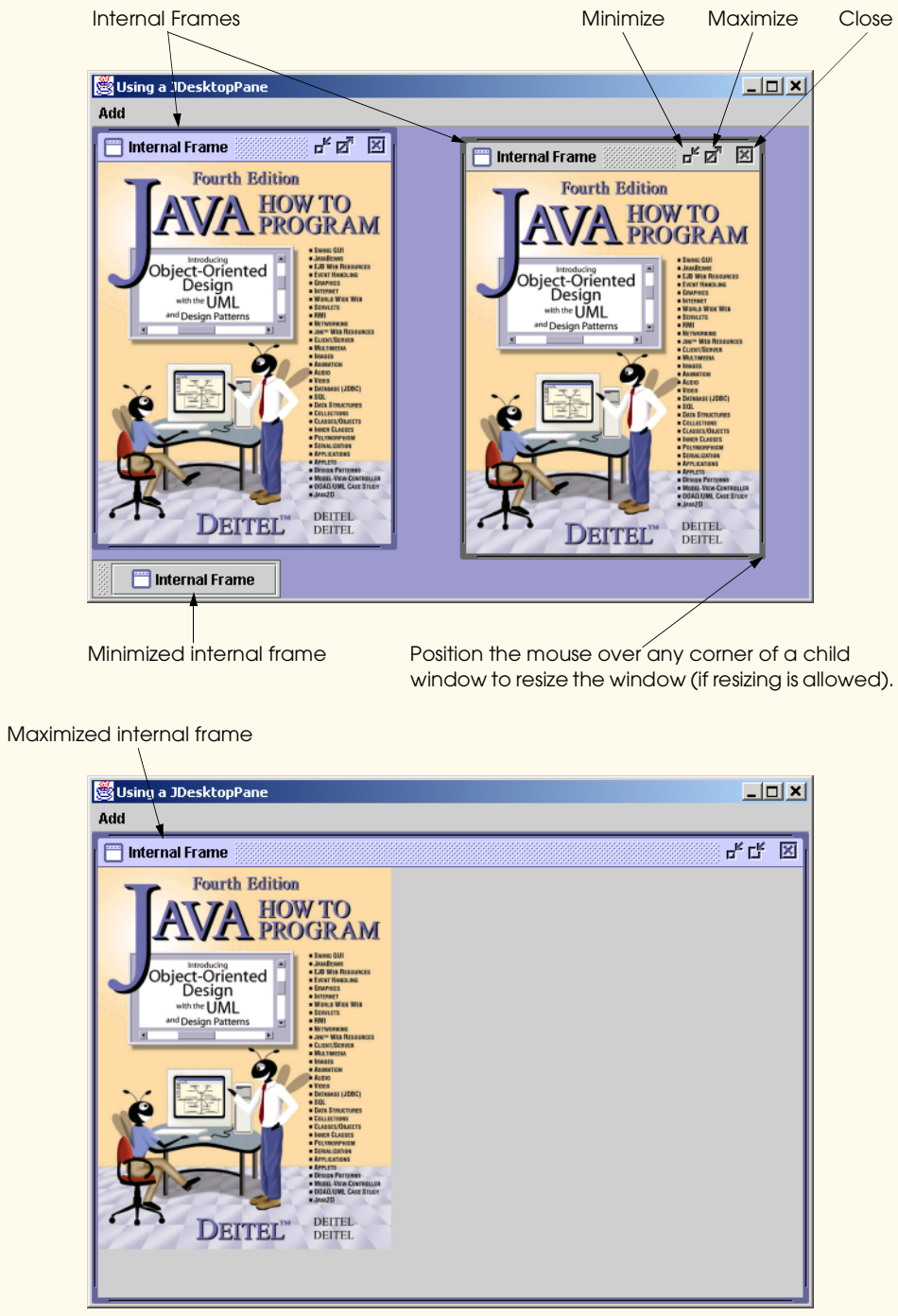


Fig. 13.13 Creating a multiple document interface (part 3 of 3).

Line 30 creates ***JDesktopPane*** (package **javax.swing**) reference **theDesktop** and assigns it a new **JDesktopPane** object. The **JDesktopPane** object manages the **JInternalFrame** child windows displayed in the **JDesktopPane**. Line 31 adds the **JDesktopPane** to the application window's content pane.

Lines 34–61 register an instance of an anonymous inner class that implements **ActionListener** to handle the event when the user selects the **newFrame** menu item. When the event occurs, method **actionPerformed** (lines 40–57) creates a **JInternalFrame** object with lines 43–44. The **JInternalFrame** constructor used here requires five arguments—a **String** for the title bar of the internal window, a **boolean** indicating whether the internal frame should be resizable by the user, a **boolean** indicating whether the internal frame should be closable by the user, a **boolean** indicating whether the internal frame should be maximizable by the user and a **boolean** indicating whether the internal frame should be minimizable by the user. For each of the boolean arguments, a **true** value indicates that the operation should be allowed.

As with **JFrame**s and **JApplet**s, a **JInternalFrame** has a content pane to which GUI components can be attached. Line 47 gets a reference to the **JInternalFrame**'s content pane. Line 48 creates an instance of our class **MyJPanel** (defined at lines 80–106) that is added to the **JInternalFrame**'s content pane at line 49.

Line 52 uses **JInternalFrame** method ***pack*** to set the size of the child window. Method **pack** uses the preferred sizes of the components on the content pane to determine the window's size. Class **MyJPanel** defines method **getPreferredSize** to specify the panel's preferred size. Line 55 adds the **JInternalFrame** to the **JDesktopPane**, and line 56 displays the **JInternalFrame**.

Classes **JInternalFrame** and **JDesktopPane** provide many methods for managing child windows. See the on-line API documentation for a complete list of these methods.

13.12 Layout Managers

In the preceding chapter, we introduced three layout managers—**FlowLayout**, **BorderLayout** and **GridLayout**. This section presents three additional layout managers (summarized in Figure 13.14). We discuss these layout managers in the sections that follow.

Layout Manager	Description
BoxLayout	A layout manager that allows GUI components to be arranged left-to-right or top-to-bottom in a container. Class ***Box*** defines a container with **BoxLayout** as its default layout manager and provides static methods to create a **Box** with a horizontal or vertical **BoxLayout**.
CardLayout	A layout manager that stacks components like a deck of cards. If a component in the deck is a container, it can use any layout manager. Only the component at the "top" of the deck is visible.
GridBagLayout	A layout manager similar to **GridLayout**. Unlike **GridLayout**, each component size can vary and components can be added in any order.

Fig. 13.14 Additional layout managers.

13.13 BoxLayout Layout Manager

The ***BoxLayout*** *layout manager* arranges GUI components horizontally along the *x*-axis or vertically along the *y*-axis of a container. The program of Fig. 13.15 demonstrates **BoxLayout** and the container class **Box** that uses **BoxLayout** as its default layout manager.

In the constructor for class **BoxLayoutDemo**, lines 19–20 obtain a reference to the content pane and set its layout to a **BorderLayout** with 30 pixels of horizontal and 30 pixels of vertical gap space between components. The space is to help isolate each of the containers with **BoxLayout** in this example.

Lines 23–28 define an array of **Box** container references called **boxes** and initialize each element of the array with **Box** objects. Elements 0 and 2 of the array are initialized with **static** method ***createHorizontalBox*** of class **Box**, which returns a **Box** container with a horizontal **BoxLayout** (GUI components are arranged left-to-right). Elements 1 and 3 of the array are initialized with **static** method ***createVerticalBox*** of class **Box**, which returns a **Box** container with a vertical **BoxLayout** (GUI components are arranged top-to-bottom).

```
1  // Fig. 13.15: BoxLayoutDemo.java
2  // Demonstrating BoxLayout.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class BoxLayoutDemo extends JFrame {
12
13    // set up GUI
14    public BoxLayoutDemo()
15    {
16       super( "Demostrating BoxLayout" );
17       final int SIZE = 3;
18
19       Container container = getContentPane();
20       container.setLayout( new BorderLayout( 30, 30 ) );
21
22       // create Box containers with BoxLayout
23       Box boxes[] = new Box[ 4 ];
24
25       boxes[ 0 ] = Box.createHorizontalBox();
26       boxes[ 1 ] = Box.createVerticalBox();
27       boxes[ 2 ] = Box.createHorizontalBox();
28       boxes[ 3 ] = Box.createVerticalBox();
29
30       // add buttons to boxes[ 0 ]
31       for ( int count = 0; count < SIZE; count++ )
32          boxes[ 0 ].add( new JButton( "boxes[0]: " + count ) );
```

Fig. 13.15 Demonstrating the **BoxLayout** layout manager (part 1 of 3).

```
33
34          // create strut and add buttons to boxes[ 1 ]
35          for ( int count = 0; count < SIZE; count++ ) {
36             boxes[ 1 ].add( Box.createVerticalStrut( 25 ) );
37             boxes[ 1 ].add( new JButton( "boxes[1]: " + count ) );
38          }
39
40          // create horizontal glue and add buttons to boxes[ 2 ]
41          for ( int count = 0; count < SIZE; count++ ) {
42             boxes[ 2 ].add( Box.createHorizontalGlue() );
43             boxes[ 2 ].add( new JButton( "boxes[2]: " + count ) );
44          }
45
46          // create rigid area and add buttons to boxes[ 3 ]
47          for ( int count = 0; count < SIZE; count++ ) {
48             boxes[ 3 ].add(
49                Box.createRigidArea( new Dimension( 12, 8 ) ) );
50             boxes[ 3 ].add( new JButton( "boxes[3]: " + count ) );
51          }
52
53          // create vertical glue and add buttons to panel
54          JPanel panel = new JPanel();
55          panel.setLayout(
56             new BoxLayout( panel, BoxLayout.Y_AXIS ) );
57
58          for ( int count = 0; count < SIZE; count++ ) {
59             panel.add( Box.createGlue() );
60             panel.add( new JButton( "panel: " + count ) );
61          }
62
63          // place panels on frame
64          container.add( boxes[ 0 ], BorderLayout.NORTH );
65          container.add( boxes[ 1 ], BorderLayout.EAST );
66          container.add( boxes[ 2 ], BorderLayout.SOUTH );
67          container.add( boxes[ 3 ], BorderLayout.WEST );
68          container.add( panel, BorderLayout.CENTER );
69
70          setSize( 350, 300 );
71          setVisible( true );
72
73       }  // end constructor
74
75       // execute application
76       public static void main( String args[] )
77       {
78          BoxLayoutDemo application = new BoxLayoutDemo();
79
80          application.setDefaultCloseOperation(
81             JFrame.EXIT_ON_CLOSE );
82       }
83
84    }  // end class BoxLayoutDemo
```

Fig. 13.15 Demonstrating the **BoxLayout** layout manager (part 2 of 3).

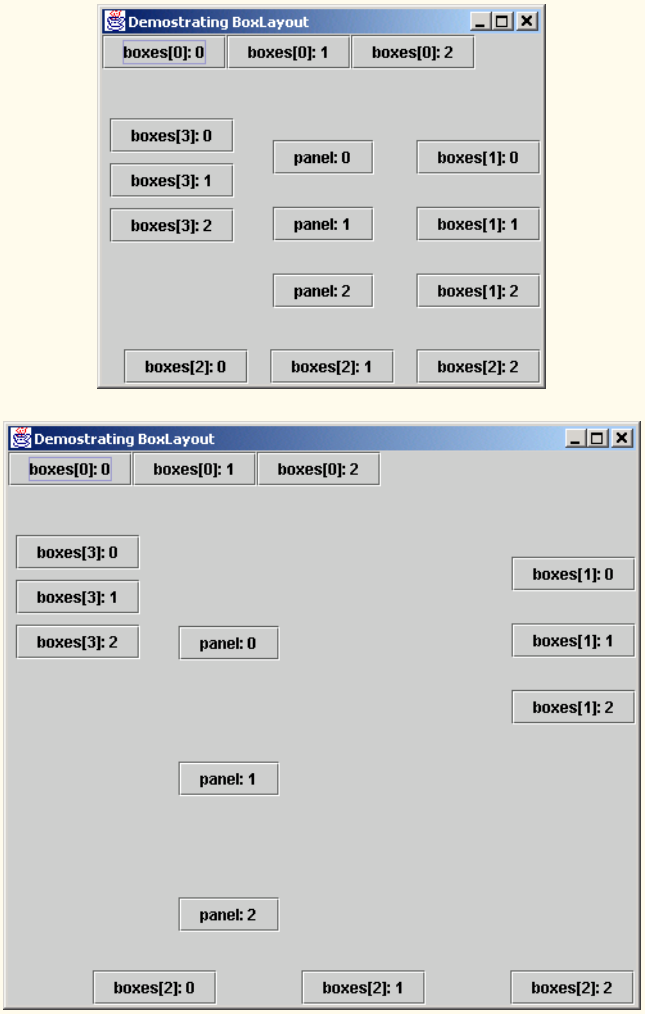


Fig. 13.15 Demonstrating the **BoxLayout** layout manager (part 3 of 3).

The **for** structure at lines 31–32 adds three **JButton**s to **boxes[0]** (a horizontal **Box**). The **for** structure at lines 35–38 adds three **JButton**s to **boxes[1]** (a vertical **Box**). Before adding each button, line 36 adds a *vertical strut* to the container with **static** method ***createVerticalStrut*** of class **Box**. A vertical strut is an invisible GUI component that has a fixed pixel height and is used to guarantee a fixed amount of space between GUI components. The argument to method **createVerticalStrut** determines the height of the strut in pixels. Class **Box** also defines method ***createHorizontalStrut*** for horizontal **BoxLayout**s.

The **for** structure at lines 41–44 adds three **JButton**s to **boxes[2]** (a horizontal **Box**). Before adding each button, line 42 adds *horizontal glue* to the container with **static** method ***createHorizontalGlue*** of class **Box**. Horizontal glue is an invis-

ible GUI component that can be used between fixed-size GUI components to occupy additional space. Normally, extra space appears to the right of the last horizontal GUI component or below the last vertical GUI component in a **BoxLayout**. Glue allows the extra space to be placed between GUI components. Class **Box** also defines method ***createVerticalGlue*** for vertical **BoxLayout**s.

The **for** structure at lines 47–51 adds three **JButton**s to **boxes[3]** (a vertical **Box**). Before adding each button, lines 48–49 add a *rigid area* to the container with **static** method ***createRigidArea*** of class **Box**. A rigid area is an invisible GUI component that always has a fixed pixel width and height. The argument to method **createRigidArea** is a **Dimension** object that specifies the width and height of the rigid area.

Lines 54–56 create a **JPanel** object and set its layout in the conventional manner, using **Container** method **setLayout**. The **BoxLayout** constructor receives a reference to the container for which it controls the layout and a constant indicating whether the layout is horizontal (***BoxLayout.X_AXIS***) or vertical (***BoxLayout.Y_AXIS***).

The **for** structure at lines 58–61 adds three **JButton**s to **panel**.Before adding each button, line 59 adds a glue component to the container with **static** method ***createGlue*** of class **Box**. This component expands or contracts based on the size of the **Box**.

The **Box** containers and the **JPanel** are attached to the content pane's **BorderLayout** at lines 64–68. Try executing the application. When the window appears, resize the window to see how the glue components, strut components and rigid area affect the layout in each container.

13.14 CardLayout Layout Manager

The ***CardLayout layout manager*** arranges components into a "deck" of cards where only the top card is visible. Any card in the deck can be placed at the top of the deck at any time by using methods of class **CardLayout**. Each card is usually a container, such as a panel, and each card can use any layout manager. Class **CardLayout** inherits from **Object** and implements the **LayoutManager2** interface.

The program of Fig. 13.16 creates five panels. **JPanel deck** uses the **CardLayout** layout manager to control the card that is displayed. **JPanel**s **card1**, **card2** and **card3** are the individual cards in **deck**. **JPanel buttons** contains four buttons (with labels **First card**, **Next card**, **Previous card** and **Last card**) that enable the user to manipulate the deck. When the user clicks the **First card** button, the first card in **deck** (i.e., **card1**) is displayed. When the user clicks the **Last card** button, the last card (i.e., **card3**) in **deck** is displayed. Each time the user clicks the **Previous card** button, the previous card in **deck** is displayed. Each time the user clicks the **Next card** button, the next card in **deck** is displayed. Clicking the **Previous card** button or the **Next card** button repeatedly allows the user to cycle through the **deck** of cards. Application class **CardDeck** implements **ActionListener**, so the action events generated by the **JButton**s on **JPanel buttons** are handled by the application in its **actionPerformed** method.

Class **CardDeck** declares a reference of type **CardLayout** called **cardManager** (line 13). This reference is used to invoke **CardLayout** methods that manipulate the cards in the deck.

```
1  // Fig. 13.16: CardDeck.java
2  // Demonstrating CardLayout.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class CardDeck extends JFrame implements ActionListener {
12
13    private CardLayout cardManager;
14    private JPanel deck;
15    private JButton controls[];
16    private String names[] = { "First card", "Next card",
17       "Previous card", "Last card" };
18
19    // set up GUI
20    public CardDeck()
21    {
22       super( "CardLayout " );
23
24       Container container = getContentPane();
25
26       // create the JPanel with CardLayout
27       deck = new JPanel();
28       cardManager = new CardLayout();
29       deck.setLayout( cardManager );
30
31       // set up card1 and add it to JPanel deck
32       JLabel label1 =
33          new JLabel( "card one", SwingConstants.CENTER );
34       JPanel card1 = new JPanel();
35       card1.add( label1 );
36       deck.add( card1, label1.getText() ); // add card to deck
37
38       // set up card2 and add it to JPanel deck
39       JLabel label2 =
40          new JLabel( "card two", SwingConstants.CENTER );
41       JPanel card2 = new JPanel();
42       card2.setBackground( Color.yellow );
43       card2.add( label2 );
44       deck.add( card2, label2.getText() ); // add card to deck
45
46       // set up card3 and add it to JPanel deck
47       JLabel label3 = new JLabel( "card three" );
48       JPanel card3 = new JPanel();
49       card3.setLayout( new BorderLayout() );
50       card3.add( new JButton( "North" ), BorderLayout.NORTH );
51       card3.add( new JButton( "West" ), BorderLayout.WEST );
52       card3.add( new JButton( "East" ), BorderLayout.EAST );
53       card3.add( new JButton( "South" ), BorderLayout.SOUTH );
```

Fig. 13.16 Demonstrating the **CardLayout** layout manager (part 1 of 3).

```
54          card3.add( label3, BorderLayout.CENTER );
55          deck.add( card3, label3.getText() ); // add card to deck
56
57          // create and layout buttons that will control deck
58          JPanel buttons = new JPanel();
59          buttons.setLayout( new GridLayout( 2, 2 ) );
60          controls = new JButton[ names.length ];
61
62          for ( int count = 0; count < controls.length; count++ ) {
63             controls[ count ] = new JButton( names[ count ] );
64             controls[ count ].addActionListener( this );
65             buttons.add( controls[ count ] );
66          }
67
68          // add JPanel deck and JPanel buttons to the applet
69          container.add( buttons, BorderLayout.WEST );
70          container.add( deck, BorderLayout.EAST );
71
72          setSize( 450, 200 );
73          setVisible( true );
74
75       }  // end constructor
76
77       // handle button events by switching cards
78       public void actionPerformed( ActionEvent event )
79       {
80          // show first card
81          if ( event.getSource() == controls[ 0 ] )
82             cardManager.first( deck );
83
84          // show next card
85          else if ( event.getSource() == controls[ 1 ] )
86             cardManager.next( deck );
87
88          // show previous card
89          else if ( event.getSource() == controls[ 2 ] )
90             cardManager.previous( deck );
91
92          // show last card
93          else if ( event.getSource() == controls[ 3 ] )
94             cardManager.last( deck );
95       }
96
97       // execute application
98       public static void main( String args[] )
99       {
100         CardDeck cardDeckDemo = new CardDeck();
101
102         cardDeckDemo.setDefaultCloseOperation(
103            JFrame.EXIT_ON_CLOSE );
104      }
105
106   }  // end class CardDeck
```

Fig. 13.16 Demonstrating the **`CardLayout`** layout manager (part 2 of 3).

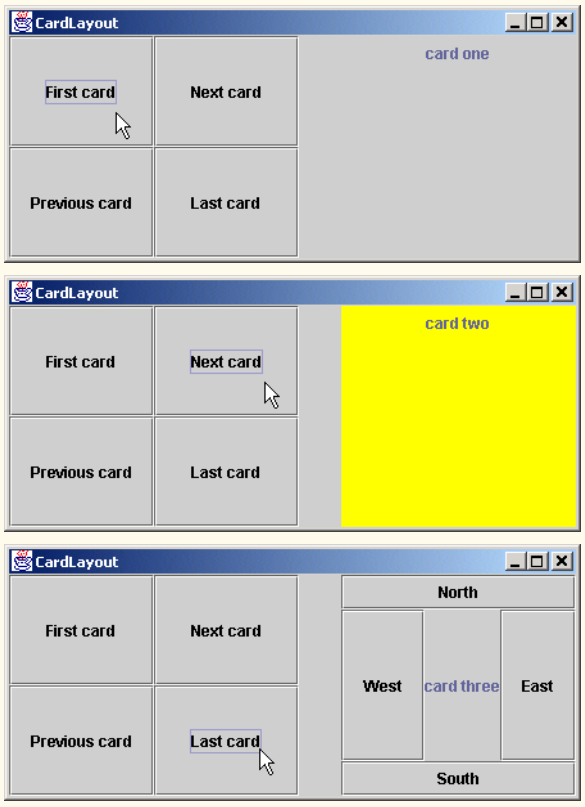


Fig. 13.16 Demonstrating the **`CardLayout`** layout manager (part 3 of 3).

The constructor method (lines 20–75) builds the GUI. Lines 27–29 create **`JPanel deck`**, create **`CardLayout`** object **`cardManager`** and set the layout manager for **`deck`** to **`cardManager`**. Next, the constructor creates the **`JPanel`**s **`card1`**, **`card2`**, and **`card3`** and their GUI components. As we set up each card, we add the card to **`deck`**, using **`Container`** method **`add`** with two arguments—a **`Component`** and a **`String`**. The **`Component`** is the **`JPanel`** object that represents the card. The **`String`** argument identifies the card. For example, line 36 adds **`JPanel card1`** to deck and uses **`JLabel label1`**'s label as the **`String`** identifier for the card. **`JPanel`**s **`card2`** and **`card3`** are added to **`deck`** at lines 44–55. Next, the constructor creates the **`JPanel buttons`** and its **`JButton`** objects (lines 58–66). Line 64 registers the **`ActionListener`** for each **`JButton`**. Finally, **`buttons`** and **`deck`** are added to the content pane's **`WEST`** and **`EAST`** regions, respectively.

Method **`actionPerformed`** (lines 78–95) determines which **`JButton`** generated the event by using **`EventObject`** method **`getSource`**. **`CardLayout`** methods ***`first`***, ***`previous`***, ***`next`*** and ***`last`*** are used to display the particular card corresponding to which **`JButton`** the user pressed. Method **`first`** displays the first card added to the deck. Method **`previous`** displays the previous card in the deck. Method **`next`** displays the next card in the deck. Method **`last`** displays the last card in the deck. Note that **`deck`** is passed to each of these methods.

13.15 `GridBagLayout` Layout Manager

The most complex and most powerful of the predefined layout managers is ***`GridBagLayout`***. This layout is similar to **`GridLayout`** because **`GridBagLayout`** also arranges components in a grid. However, **`GridBagLayout`** is more flexible. The components can vary in size (i.e., they can occupy multiple rows and columns) and can be added in any order.

The first step in using **`GridBagLayout`** is determining the appearance of the GUI. This step does not involve any programming; all that is needed is a piece of paper. First, draw the GUI. Next draw a grid over the GUI dividing the components into rows and columns. The initial row and column numbers should be 0 so the **`GridBagLayout`** layout manager can properly place the components in the grid. The row and column numbers will be used to place each component in an exact position in the grid. Figure 13.17 demonstrates drawing the lines for the rows and columns over a GUI.

To use **`GridBagLayout`**, a ***`GridBagConstraints`*** object must be constructed. This object specifies how a component is placed in a **`GridBagLayout`**. Several **`GridBagConstraints`** instance variables are summarized in Fig. 13.18.

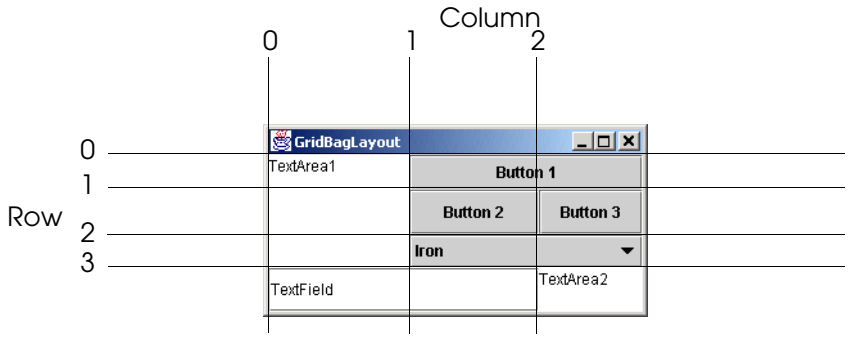


Fig. 13.17 Designing a GUI that will use **`GridBagLayout`**.

`GridBagConstraints` Instance Variable	Description
`gridx`	The column in which the component will be placed.
`gridy`	The row in which the component will be placed.
`gridwidth`	The number of columns the component occupies.
`gridheight`	The number of rows the component occupies.
`weightx`	The portion of extra space to allocate horizontally. The components can become wider when extra space is available.
`weighty`	The portion of extra space to allocate vertically. The components can become taller when extra space is available.

Fig. 13.18 **`GridBagConstraints`** instance variables.

Variables ***gridx*** and ***gridy*** specify the row and column where the upper-left corner of the component is placed in the grid. Variable **gridx** corresponds to the column and the variable **gridy** corresponds to the row. In Fig. 13.17, the **JComboBox** (displaying "**Iron**") has a **gridx** value of 1 and a **gridy** value of 2.

Variable ***gridwidth*** specifies the number of columns a component occupies. In Fig. 13.17, the **JComboBox** button occupies two columns. Variable ***gridheight*** specifies the number of rows a component occupies. In Fig. 13.17, the **JTextArea** on the left side of the window occupies three rows.

Variable ***weightx*** specifies how to distribute extra horizontal space to components in a **GridBagLayout** when the container is resized. A zero value indicates that the component does not grow horizontally on its own. However, if the component spans a column containing a component with nonzero **weightx** value, the component with zero **weightx** value will grow horizontally in the same proportion as the other component(s) in the same column. This is because each component must be maintained in the same row and column in which it was originally placed.

Variable ***weighty*** specifies how to distribute extra vertical space to components in a **GridBagLayout** when the container is resized. A zero value indicates that the component does not grow vertically on its own. However, if the component spans a row containing a component with nonzero **weighty** value, the component with zero **weighty** value grows vertically in the same proportion as the other component(s) in the same row.

In Fig. 13.17, the effects of **weighty** and **weightx** cannot easily be seen until the container is resized and additional space becomes available. Components with larger weight values occupy more of the additional space than components with smaller weight values. The exercises explore the effects of varying **weightx** and **weighty**.

Components should be given nonzero positive weight values—otherwise the components will "huddle" together in the middle of the container. Figure 13.19 shows the GUI of Fig. 13.17—where all weights have been set to zero.

Common Programming Error 13.6

*Using a negative value for either **weightx** or **weighty** is a logic error.*

GridBagConstraints instance variable ***fill*** specifies how much of the component's area (the number of rows and columns the component occupies in the grid) is occupied. The variable **fill** is assigned one of the following **GridBagConstraints** constants: ***NONE***, ***VERTICAL***, ***HORIZONTAL*** or ***BOTH***. The default value is **NONE**, which indicates that the component will not grow in either direction. **VERTICAL** indicates that the component will grow vertically. **HORIZONTAL** indicates that the component will grow horizontally. **BOTH** indicates that the component will grow in both directions.

GridBagConstraints instance variable ***anchor*** specifies the location of the component in the area when the component does not fill the entire area. The variable **anchor** is assigned one of the following **GridBagConstraints** constants: ***NORTH***, ***NORTHEAST***, ***EAST***, ***SOUTHEAST***, ***SOUTH***, ***SOUTHWEST***, ***WEST***, ***NORTHWEST*** or ***CENTER***. The default value is **CENTER**.

The program of Fig. 13.20 uses the **GridBagLayout** layout manager to arrange the components in the GUI of Fig. 13.17. The program does nothing other than demonstrate how to use **GridBagLayout**.

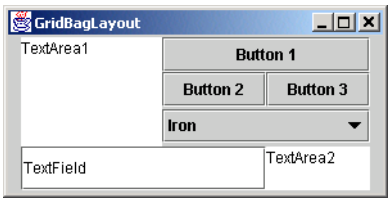


Fig. 13.19 **GridBagLayout** with the weights set to zero.

```
1  // Fig. 13.20: GridBagDemo.java
2  // Demonstrating GridBagLayout.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class GridBagDemo extends JFrame {
12    private Container container;
13    private GridBagLayout layout;
14    private GridBagConstraints constraints;
15
16    // set up GUI
17    public GridBagDemo()
18    {
19       super( "GridBagLayout" );
20
21       container = getContentPane();
22       layout = new GridBagLayout();
23       container.setLayout( layout );
24
25       // instantiate gridbag constraints
26       constraints = new GridBagConstraints();
27
28       // create GUI components
29       JTextArea textArea1 = new JTextArea( "TextArea1", 5, 10 );
30       JTextArea textArea2 = new JTextArea( "TextArea2", 2, 2 );
31
32       String names[] = { "Iron", "Steel", "Brass" };
33       JComboBox comboBox = new JComboBox( names );
34
35       JTextField textField = new JTextField( "TextField" );
36       JButton button1 = new JButton( "Button 1" );
37       JButton button2 = new JButton( "Button 2" );
38       JButton button3 = new JButton( "Button 3" );
```

Fig. 13.20 Demonstrating the **GridBagLayout** layout manager (part 1 of 3).

```
39
40          // textArea1
41          // weightx and weighty are both 0: the default
42          // anchor for all components is CENTER: the default
43          constraints.fill = GridBagConstraints.BOTH;
44          addComponent( textArea1, 0, 0, 1, 3 );
45
46          // button1
47          // weightx and weighty are both 0: the default
48          constraints.fill = GridBagConstraints.HORIZONTAL;
49          addComponent( button1, 0, 1, 2, 1 );
50
51          // comboBox
52          // weightx and weighty are both 0: the default
53          // fill is HORIZONTAL
54          addComponent( comboBox, 2, 1, 2, 1 );
55
56          // button2
57          constraints.weightx = 1000;  // can grow wider
58          constraints.weighty = 1;     // can grow taller
59          constraints.fill = GridBagConstraints.BOTH;
60          addComponent( button2, 1, 1, 1, 1 );
61
62          // button3
63          // fill is BOTH
64          constraints.weightx = 0;
65          constraints.weighty = 0;
66          addComponent( button3, 1, 2, 1, 1 );
67
68          // textField
69          // weightx and weighty are both 0, fill is BOTH
70          addComponent( textField, 3, 0, 2, 1 );
71
72          // textArea2
73          // weightx and weighty are both 0, fill is BOTH
74          addComponent( textArea2, 3, 2, 1, 1 );
75
76          setSize( 300, 150 );
77          setVisible( true );
78       }
79
80       // method to set constraints on
81       private void addComponent( Component component,
82          int row, int column, int width, int height )
83       {
84          // set gridx and gridy
85          constraints.gridx = column;
86          constraints.gridy = row;
87
88          // set gridwidth and gridheight
89          constraints.gridwidth = width;
90          constraints.gridheight = height;
91
```

Fig. 13.20 Demonstrating the **`GridBagLayout`** layout manager (part 2 of 3).

```
92          // set constraints and add component
93          layout.setConstraints( component, constraints );
94          container.add( component );
95       }
96
97       // execute application
98       public static void main( String args[] )
99       {
100         GridBagDemo application = new GridBagDemo();
101
102         application.setDefaultCloseOperation(
103            JFrame.EXIT_ON_CLOSE );
104      }
105
106   }  // end class GridBagDemo
```

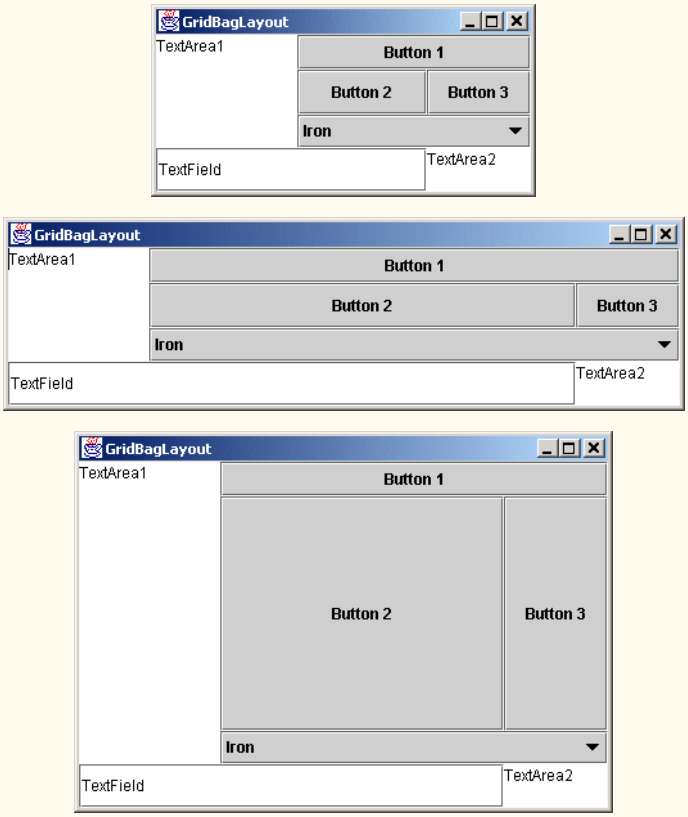


Fig. 13.20 Demonstrating the **GridBagLayout** layout manager (part 3 of 3).

The GUI consists of three **JButton**s, two **JTextArea**s, a **JComboBox** and a **JTextField**. The layout manager for the content pane is **GridBagLayout**. Lines 22–23 instantiate the **GridBagLayout** object and set the layout manager for the content pane to **layout**. The **GridBagConstraints** object used to determine the location and size

of each component in the grid is instantiated with line 26. Lines 23 through 30 instantiate each of the GUI components that will be added to the content pane.

JTextArea textArea1 is the first component added to the **GridBagLayout** (line 44). The values for **weightx** and **weighty** values are not specified in **gbConstraints**, so each has the value zero by default. Thus, the **JTextArea** will not resize itself even if space is available. However, the **JTextArea** spans multiple rows, so the vertical size is subject to the **weighty** values of **JButton**s **button2** and **button3**. When either **button2** or **button3** is resized vertically based on its **weighty** value, the **JTextArea** is also resized.

Line 43 sets variable **fill** in **constraints** to **GridBagConstraints.BOTH**, causing the **JTextArea** to always fill its entire allocated area in the grid. An **anchor** value is not specified in **constraints**, so the default **CENTER** is used. We do not use variable **anchor** in this program, so all components will use the default. Line 36 calls our utility method ***addComponent*** method (defined at lines 81–95). The **JTextArea** object, the row, the column, the number of columns to span and the number of rows to span are passed as arguments.

Method **addComponent**'s parameters are a **Component** reference **component** and integers **row**, **column**, **width** and **height**. Lines 85–86 set the **GridBagConstraints** variables **gridx** and **gridy**. The **gridx** variable is assigned the column in which the **Component** will be placed, and the **gridy** value is assigned the row in which the **Component** will be placed. Lines 89–90 set the **GridBagConstraints** variables **gridwidth** and **gridheight**. The **gridwidth** variable specifies the number of columns the **Component** will span in the grid and the **gridheight** variable specifies the number of rows the **Component** will span in the grid. Line 93 sets the **GridBagConstraints** for a component in the **GridBagLayout**. Method ***setConstraints*** of class **GridBagLayout** takes a **Component** argument and a **GridBagConstraints** argument. Method **add** (line 94) is used to add the component to the content pane.

JButton object **button1** is the next component added (lines 48–49). The values of **weightx** and **weighty** are still zero. The **fill** variable is set to **HORIZONTAL**—the component will always fill its area in the horizontal direction. The vertical direction is not filled. The **weighty** value is zero, so the button will become taller only if another component in the same row has a nonzero **weighty** value. **JButton b1** is located at row 0, column 1. One row and two columns are occupied.

JComboBox comboBox is the next component added (line 54). The **weightx** and **weighty** values are zero, and the **fill** variable is set to **HORIZONTAL**. The **JComboBox** button will grow only in the horizontal direction. Note that the **weightx**, **weighty** and **fill** variables remain set in **gbConstraints** until they are changed. The **JComboBox** button is placed at row 2, column 1. One row and two columns are occupied.

JButton object **button2** is the next component added (lines 57–60). **JButton button2** is given a **weightx** value of **1000** and a **weighty** value of **1**. The area occupied by the button is capable of growing in the vertical and horizontal directions. The **fill** variable is set to **BOTH**, which specifies that the button will always fill the entire area. When the window is resized, **b2** will grow. The button is placed at row 1, column 1. One row and one column are occupied.

JButton button3 is added next (lines 64–66). Both the **weightx** value and **weighty** value are set to zero, and the value of **fill** is **BOTH**. **JButton button3** will

grow if the window is resized; it is affected by the weight values of **button2**. Note that the **weightx** value for **button2** is much larger than **button3**. When resizing occurs, **button2** will occupy a larger percentage of the new space. The button is placed at row 1, column 2. One row and one column are occupied.

Both the **JTextField** (line 70) and **JTextArea textArea2** (line 74) have a **weightx** value 0 and a **weighty** value 0. The value of **fill** is **BOTH**. The **JTextField** is placed at row 3, column 0, and the **JTextArea** is placed at row 3, column 2. The **JTextField** occupies one row and two columns. The **JTextArea** occupies one row and one column.

When you execute this application, try resizing the window to see how the constraints for each GUI component affect its position and size in the window.

13.16 GridBagConstraints Constants RELATIVE and REMAINDER

A variation of **GridBagLayout** does not use **gridx** and **gridy**. Rather, **GridbagConstraints** constants ***RELATIVE*** and ***REMAINDER*** are used in their place. **RELATIVE** specifies that the next-to-last component in a particular row should be placed to the right of the previous component in that row. **REMAINDER** specifies that a component is the last component in a row. Any component that is not the second-to-last or last component on a row must specify values for **GridbagConstraints** variables **gridwidth** and **gridheight**. Class **GridBagDemo2** in Fig. 13.21 arranges components in **GridBagLayout**, using these constants.

```
1  // Fig. 13.21: GridBagDemo2.java
2  // Demonstrating GridBagLayout constants.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class GridBagDemo2 extends JFrame {
12    private GridBagLayout layout;
13    private GridBagConstraints constraints;
14    private Container container;
15
16    // set up GUI
17    public GridBagDemo2()
18    {
19       super( "GridBagLayout" );
20
21       container = getContentPane();
22       layout = new GridBagLayout();
23       container.setLayout( layout );
24
```

Fig. 13.21 Demonstrating the **GridBagConstraints** constants **RELATIVE** and **REMAINDER** (part 1 of 3).

```
25          // instantiate gridbag constraints
26          constraints = new GridBagConstraints();
27
28          // create GUI components
29          String metals[] = { "Copper", "Aluminum", "Silver" };
30          JComboBox comboBox = new JComboBox( metals );
31
32          JTextField textField = new JTextField( "TextField" );
33
34          String fonts[] = { "Serif", "Monospaced" };
35          JList list = new JList( fonts );
36
37          String names[] =
38             { "zero", "one", "two", "three", "four" };
39          JButton buttons[] = new JButton[ names.length ];
40
41          for ( int count = 0; count < buttons.length; count++ )
42             buttons[ count ] = new JButton( names[ count ] );
43
44          // define GUI component constraints
45          // textField
46          constraints.weightx = 1;
47          constraints.weighty = 1;
48          constraints.fill = GridBagConstraints.BOTH;
49          constraints.gridwidth = GridBagConstraints.REMAINDER;
50          addComponent( textField );
51
52          // buttons[0] -- weightx and weighty are 1: fill is BOTH
53          constraints.gridwidth = 1;
54          addComponent( buttons[ 0 ] );
55
56          // buttons[1] -- weightx and weighty are 1: fill is BOTH
57          constraints.gridwidth = GridBagConstraints.RELATIVE;
58          addComponent( buttons[ 1 ] );
59
60          // buttons[2] -- weightx and weighty are 1: fill is BOTH
61          constraints.gridwidth = GridBagConstraints.REMAINDER;
62          addComponent( buttons[ 2 ] );
63
64          // comboBox -- weightx is 1: fill is BOTH
65          constraints.weighty = 0;
66          constraints.gridwidth = GridBagConstraints.REMAINDER;
67          addComponent( comboBox );
68
69          // buttons[3] -- weightx is 1: fill is BOTH
70          constraints.weighty = 1;
71          constraints.gridwidth = GridBagConstraints.REMAINDER;
72          addComponent( buttons[ 3 ] );
73
74          // buttons[4] -- weightx and weighty are 1: fill is BOTH
75          constraints.gridwidth = GridBagConstraints.RELATIVE;
76          addComponent( buttons[ 4 ] );
```

Fig. 13.21 Demonstrating the **`GridBagConstraints`** constants **`RELATIVE`** and **`REMAINDER`** (part 2 of 3).

```
77
78          // list -- weightx and weighty are 1: fill is BOTH
79          constraints.gridwidth = GridBagConstraints.REMAINDER;
80          addComponent( list );
81
82          setSize( 300, 200 );
83          setVisible( true );
84
85       }  // end constructor
86
87       // addComponent is programmer-defined
88       private void addComponent( Component component )
89       {
90          layout.setConstraints( component, constraints );
91          container.add( component );      // add component
92       }
93
94       // execute application
95       public static void main( String args[] )
96       {
97          GridBagDemo2 application = new GridBagDemo2();
98
99          application.setDefaultCloseOperation(
100            JFrame.EXIT_ON_CLOSE );
101      }
102
103   }  // end class GridBagDemo2
```

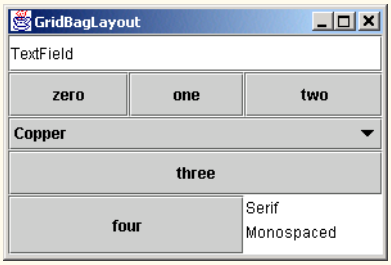


Fig. 13.21 Demonstrating the **GridBagConstraints** constants **RELATIVE** and **REMAINDER** (part 3 of 3).

Lines 22–23 construct a **GridBagLayout** and set the content pane's layout manager to **GridBagLayout**. The components that are placed in **GridBagLayout** are each constructed (lines 29–42). The components are five **JButton**s, one **JTextField**, one **JList** and one **JComboBox**.

The **JTextField** is added first (lines 46–50). The **weightx** and **weighty** values are set to 1. The **fill** variable is set to **BOTH**. Line 49 specifies that the **JTextField** is the last component on the line. The **JTextField** is added to the content pane with a call to our utility method **addComponent** (defined at lines 88–92). Method **addComponent** takes a **Component** argument and uses **GridBagLayout** method **setConstraints** to set the constraints for the **Component**. Method **add** attaches the component to the content pane.

JButton buttons[0] (lines 53–54) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. Because **buttons[0]** is not one of the last two components on the row, it is given a **gridwidth** of 1 so it will occupy one column. The **JButton** is added to the content pane with a call to utility method **addComponent**.

JButton buttons[1] (lines 57–58) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. Line 57 specifies that the **JButton** is to be placed relative to the previous component. The **Button** is added to the **JFrame** with a call to **addComponent**.

JButton buttons[2] (lines 61–62) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. This **JButton** is the last component on the line, so **REMAINDER** is used. The **JButton** is added to the content pane with a call to utility method **addComponent**.

The **JComboBox** button (lines 65–67) has a **weightx** 1 and a **weighty** 0. The **JComboBox** will not grow in the vertical direction. The **JComboBox** is the only component on the line, so **REMAINDER** is used. The **JComboBox** is added to the content pane with a call to utility method **addComponent**.

JButton buttons[3] (lines 70–72) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. This **JButton** is the only component on the line, so **REMAINDER** is used. The **JButton** is added to the content pane with a call to utility method **addComponent**.

JButton buttons[4] (lines 75–76) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. This **JButton** is the next-to-last component on the line, so **RELATIVE** is used. The **JButton** is added to the content pane with a call to utility method **addComponent**.

The **JList** component (lines 79–80) has **weightx** and **weighty** values of 1. The **fill** variable is **BOTH**. The **JList** is added to the content pane with a call to utility method **addComponent**.

13.17 (Optional Case Study) Thinking About Objects: Model-View-Controller

Design patterns describe proven strategies for building reliable object-oriented software systems. Our case study adheres to the *Model-View-Controller* (MVC) architecture, which uses several design patterns.[1] MVC divides system responsibilities into three parts:

1. the *model*, which contains all program data and logic;
2. the *view*, which provides a visual presentation of the model and
3. the *controller*, which defines the system behavior by sending user input to the model.

Using the controller, the user changes the data in the model. The model then informs the view of the change in data. The view changes its visual presentation to reflect the changes in the model.

For example, in our simulation, the user adds a **Person** to the model by pressing either the **First Floor** or **Second Floor** **JButton** in the controller (see Fig. 2.22–

1. For those readers who seek further study in design patterns and MVC architecture, we encourage you to read our "Discovering Design Patterns" material in Sections 1.16, 9.24, 13.18, 15.13, 17.11 and 21.12

Fig. 2.24). The model then notifies the view of the **`Person`**'s creation. The view, in response to this notification, displays a **`Person`** on a **`Floor`**. The model is unaware of how the view displays the **`Person`**, and the view is unaware of how or why the model created the **`Person`**.

The MVC architecture helps construct reliable and easily modifiable systems. If we desire text-based output rather than graphical output for the elevator simulation, we may create an alternate view to produce text-based output, without altering the model or the controller. We could also provide a three-dimensional view that uses a first-person perspective to allow the user to "take part" in the simulation; such views are commonly employed in virtual-reality-based systems.

Elevator-Simulation MVC

We now apply the MVC architecture to our elevator simulation. Every UML diagram we have provided to this point (with the exception of the use-case diagram) relates to the model of our elevator system. We provide a "higher-level" class diagram of the simulation in Fig. 13.19. Class **`ElevatorSimulation`**—a **`JFrame`** subclass—aggregates one instance each of classes **`ElevatorModel`**, **`ElevatorView`** and **`ElevatorController`** to create the **`ElevatorSimulation`** application. As mentioned in "Thinking About Objects" Section 10.22, the rectangle with the upper-right corner "folded over" represents a note in the UML. In this case, each note points to a specific class (through a dotted line) to describe that class' role in the system. Classes **`ElevatorModel`**, **`ElevatorView`** and **`ElevatorController`** encapsulate all objects comprising the model, view and controller portions of our simulation, respectively.

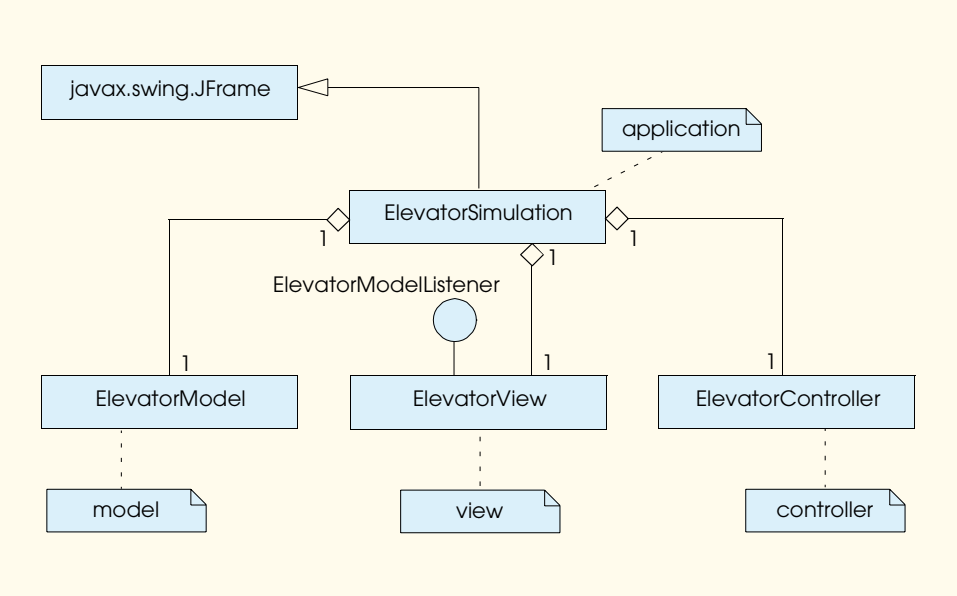


Fig. 13.19 Class diagram of the elevator simulation.

We showed in Fig. 9.38 that class **ElevatorModel** is an aggregation of several classes. To save space, we do not repeat this aggregation in Fig. 13.19. Class **ElevatorView** is also an aggregation of several classes—we expand the class diagram of **ElevatorView** in "Thinking About Objects" Section 22.9 to show these additional classes. Class **ElevatorController**, as described in Section 12.16, represents the simulation controller. Note that class **ElevatorView** implements interface **ElevatorModelListener**, which implements all interfaces used in our simulation, so the **ElevatorView** can receive all events from the model.

Software Engineering Observation 13.7

When appropriate, partition the system class diagram into several smaller class diagrams, so each diagram represents a unique subsystem.

Class **ElevatorSimulation** contains no attributes other than its references to an **ElevatorModel** object, an **ElevatorView** object and an **ElevatorController** object. The only behavior for class **ElevatorSimulation** is to start the program—therefore, in Java, class **ElevatorSimulation** contains a **static main** method that calls the constructor, which instantiates the **ElevatorModel**, **ElevatorView** and **ElevatorController** objects. We implement class **ElevatorSimulation** in Java later in this section.

Component Diagrams

Figure 13.19 helps us construct another diagram of the UML that we use to design our system—the *component diagram*. The component diagram models the "pieces"—called *components*—that the system needs to perform its tasks. These pieces include binary executables, compiled **.class** files, **.java** files, images, packages, resources, etc. We present the component diagram for our simulation in Fig. 13.20.

In Fig. 13.20, each box that contains the two small white boxes overlapping its left side is a *component*. A component in the UML is drawn similar to a plug (the two overlapping boxes represent the plug's prongs)—a component may be "plugged-in" to other systems without having to change the component. Our system contains five components: **ElevatorSimulation.class**, **ElevatorSimulation.java**, **ElevatorModel.java**, **ElevatorView.java** and **ElevatorController.java**.

In Fig. 13.20, the graphics that resemble folders (boxes with tabs in their upper-left corners) represent *packages* in the UML. We can group classes, objects, components, use cases, etc., in a package. In this diagram (and in the remainder of our case study), the UML packages refer to Java packages (introduced in Section 8.5). In our discussion, we use lower-case bold-face Courier type for package names. The packages in our system are **model**, **view** and **controller**. Component **ElevatorSimulation.java** contains one instance each of all components in these packages. Currently, each package contains only one component—a **.java** file. The **model** package contains **ElevatorModel.java**, the **view** package contains **ElevatorView.java** and the **controller** package contains **ElevatorController.java**. We add components to each package in the appendices, when we implement each class from our class diagrams into a component (**.java** file).

The dotted arrows in Fig. 13.20 indicate a *dependency* between two components—the direction of the arrow indicates the "depends on" relationship. A dependency describes the

relationship between components in which changes in one component affect another component. For example, component **`ElevatorSimulation.class`** depends on component **`ElevatorSimulation.java`**, because a change in **`ElevatorSimulation.java`** affects **`ElevatorSimulation.class`** when **`ElevatorSimulation.java`** is compiled. Section 12.16 mentioned that the **`ElevatorController`** object contains a reference to the **`ElevatorModel`** object (to place **`Person`**s on **`Floor`**s). Therefore, **`ElevatorController.java`** depends on **`ElevatorModel.java`**.

Software Engineering Observation 13.8

*A component diagram's dependencies help designers group components for reuse in future systems. For example, in our simulation, designers can reuse **`ElevatorModel.java`** in other systems without having to reuse **`ElevatorView.java`** (and vice versa), because these components do not depend on each other. However, if a designer wanted to reuse **`ElevatorController.java`**, the designer would have to reuse **`ElevatorModel.java`**.*

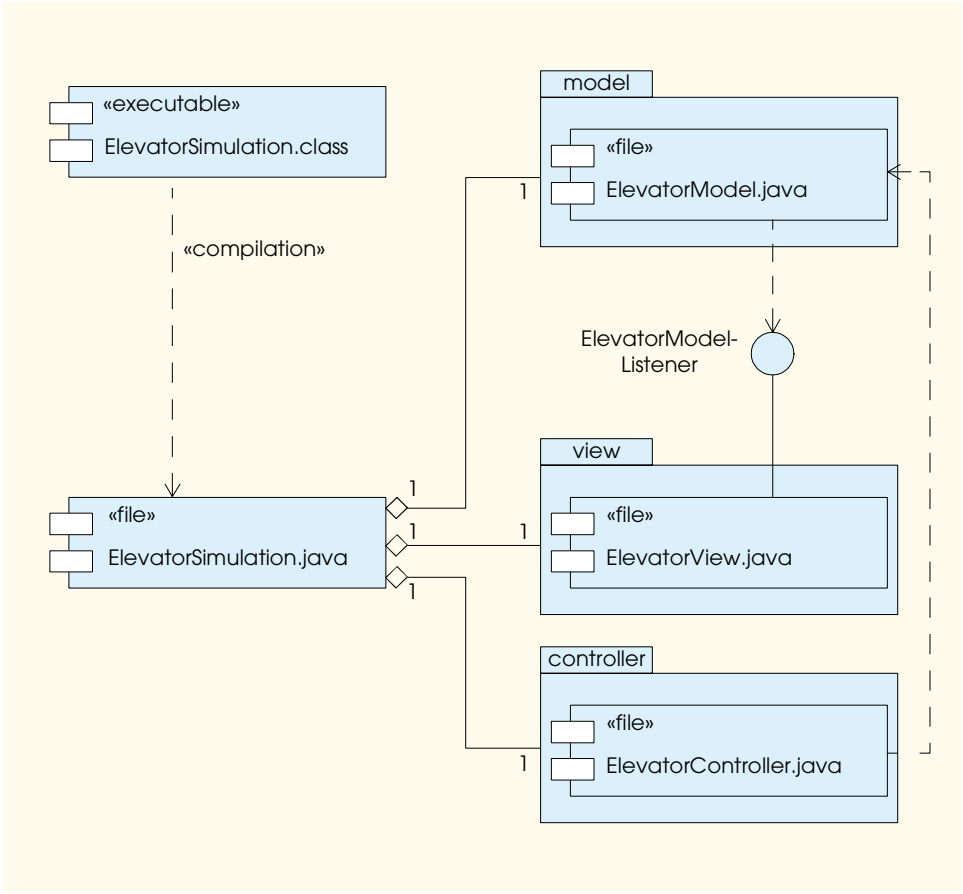


Fig. 13.20 Component diagram for elevator simulation.

According to Fig. 13.20, **ElevatorModel.java** and **ElevatorView.java** do not depend on each other—they communicate through interface **ElevatorModelListener**, which implements all interfaces in the simulation. **ElevatorView.java** realizes interface **ElevatorModelListener**, and **ElevatorModel.java** depends on interface **ElevatorModelListener**.

Figure 13.20 contains several *stereotypes*—words placed in *guillemets* (« ») indicating an element's role. We mentioned the «interface» stereotype in "Thinking About Objects" Section 11.10. The «compilation» stereotype describes the dependency between **ElevatorSimulation.class** and **ElevatorSimulation.java**—**ElevatorSimulation.java** compiles to **ElevatorSimulation.class**. The «executable» stereotype specifies that a component is an application, and the «file» stereotype specifies that a component is a file containing source code for the executable.

Implementation: ElevatorSimulation.java

We use the component diagram of Fig. 13.20, the class diagram of Fig. 13.19 and the use-case diagram of Fig. 12.28 to implement **ElevatorSimulation.java** (Fig. 13.21). Lines 12–14 import packages **model**, **view** and **controller** as specified in Fig. 13.20.

```
1  // ElevatorSimulation.java
2  // Application with Elevator Model, View, and Controller (MVC)
3  package com.deitel.jhtp4.elevator;
4
5  // Java core packages
6  import java.awt.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 // Deitel packages
12 import com.deitel.jhtp4.elevator.model.*;
13 import com.deitel.jhtp4.elevator.view.*;
14 import com.deitel.jhtp4.elevator.controller.*;
15
16 public class ElevatorSimulation extends JFrame {
17
18    // model, view and controller
19    private ElevatorModel model;
20    private ElevatorView view;
21    private ElevatorController controller;
22
23    // constructor instantiates model, view, and controller
24    public ElevatorSimulation()
25    {
26       super( "Deitel Elevator Simulation" );
27
28       // instantiate model, view and controller
29       model = new ElevatorModel();
30       view = new ElevatorView();
31       controller = new ElevatorController( model );
```

Fig. 13.21 Class **ElevatorSimulation** is the application for the elevator simulation (part 1 of 2).

```
32
33          // register View for Model events
34          model.setElevatorModelListener( view );
35
36          // add view and controller to ElevatorSimulation
37          getContentPane().add( view, BorderLayout.CENTER );
38          getContentPane().add( controller, BorderLayout.SOUTH );
39
40       } // end ElevatorSimulation constructor
41
42       // main method starts program
43       public static void main( String args[] )
44       {
45          // instantiate ElevatorSimulation
46          ElevatorSimulation simulation = new ElevatorSimulation();
47          simulation.setDefaultCloseOperation( EXIT_ON_CLOSE );
48          simulation.pack();
49          simulation.setVisible( true );
50       }
51    }
```

Fig. 13.21 Class **ElevatorSimulation** is the application for the elevator simulation (part 2 of 2).

The class diagram of Fig. 13.19 specifies that class **ElevatorSimulation** is a subclass of **javax.swing.JFrame**—line 16 declares class **ElevatorSimulation** as a **public** class extending class **JFrame**. Lines 19–21 implement class **ElevatorSimulation**'s aggregation of class **ElevatorModel**, the **ElevatorView** and the **ElevatorController** (shown in Fig. 13.19) by declaring one object from each class. Lines 29–31 of the **ElevatorSimulation** constructor initialize these objects.

Figure 13.19 and Fig. 13.20 specify that the **ElevatorView** is an **ElevatorModelListener** for the **ElevatorModel**. Line 34 registers the **ElevatorView** as a listener for **ElevatorModelEvent**s, so the **ElevatorView** can receive events from the **ElevatorModel** and properly represent the state of the model. Lines 37–38 add the **ElevatorView** and the **ElevatorController** to the **ElevatorSimulation**. According to the stereotypes in Fig. 13.20, **ElevatorSimulation.java** compiles to **ElevatorSimulation.class**, which is executable—lines 43–50 provide method **main** that runs the application.

We have completed the design of the components of our system. "Thinking About Objects" Section 15.12 concludes the design of the model by solving the interaction problems encountered in Fig. 10.26. Finally, Section 22.9 completes the design of the view and describes in greater detail how the **ElevatorView** receives events from the **ElevatorModel**. These last two sections will prepare you for the walkthrough of our elevator-simulation implementation in Appendices G, H and I.

13.18 (Optional) Discovering Design Patterns: Design Patterns Used in Packages java.awt and javax.swing

We continue our discussion from Section 9.24 on design patterns. This section introduces those design patterns associated with Java GUI components. After reading this section, you

should understand better how these components take advantage of design patterns and how developers integrate design patterns with Java GUI applications.

13.18.1 Creational Design Patterns

Now, we continue our treatment of creational design patterns, which provide ways to instantiate objects in a system.

Factory Method

Suppose we are designing a system that opens an image from a specified file. Several different image formats exist, such as GIF and JPEG. We can use method **`createImage`** of class **`java.awt.Component`** to create an **`Image`** object. For example, to create a JPEG and GIF image in an object of a **`Component`** subclass—such as a **`JPanel`** object, we pass the name of the image file to method **`createImage`**, which returns an **`Image`** object that stores the image data. We can create two **`Image`** objects, each which contains data for two images having entirely different structures. For example, a JPEG image can hold up to 16.7 million colors, whereas a GIF image can hold up to only 256. Also, a GIF image can contain transparent pixels that are not rendered on screen, whereas a JPEG image cannot contain transparent pixels.

Class **`Image`** is an abstract class that represents an image we can display on screen. Using the parameter passed by the programmer, method **`createImage`** determines the specific **`Image`** subclass from which to instantiate the **`Image`** object. We can design systems to allow the user to specify which image to create, and method **`createImage`** will determine the subclass from which to instantiate the **`Image`**. If the parameter passed to method **`createImage`** references a JPEG file, method **`createImage`** instantiates and returns an object of an **`Image`** subclass suitable for JPEG images. If the parameter references a GIF file, **`createImage`** instantiates and returns an object of an **`Image`** subclass suitable for GIF images.

Method **`createImage`** is an example of the *Factory Method design pattern*. The sole purpose of this *factory method* is to create objects by allowing the system to determine which class to instantiate at run time. We can design a system that allows a user to specify what type of image to create at run time. Class **`Component`** might not be able to determine which **`Image`** subclass to instantiate until the user specifies the image to load. For more information on method **`createImage`**, visit

```
www.java.sun.com/j2se/1.3/docs/api/java/awt/Compo-
nent.html#createImage(java.awt.image.ImageProducer)
```

13.18.2 Structural Design Patterns

We now discuss three more structural design patterns. The Adapter design pattern helps objects with incompatible interfaces collaborate with one another. The Bridge design pattern helps designers enhance platform independence in their systems. The Composite design pattern provides a way for designers to organize and manipulate objects.

Adapter

The *Adapter design pattern* provides an object with a new interface that *adapts* to another object's interface, allowing both objects to collaborate with one another. The adapter in this

pattern is similar to an adapter for a plug on an electrical device—electrical sockets in Europe are different from those in the United States, so an adapter is needed to plug an American device into a European electrical socket and vice versa.

Java provides several classes that use the Adapter design pattern. Objects of these classes act as adapters between objects that generate certain events and those objects that handle these events. For example, a **`MouseAdapter`**, which we explained in Section 12.12, adapts an object that generates **`MouseEvent`**s to an object that handles **`MouseEvent`**s.

Bridge

Suppose we are designing class **`Button`** for both the Windows and Macintosh operating systems. Class **`Button`** contains specific button information such as an **`ActionListener`** and a **`String`** label. We design classes **`Win32Button`** and **`MacButton`** to extend class **`Button`**. Class **`Win32Button`** contains "look-and-feel" information on how to display a **`Button`** on the Windows operating system and class **`MacButton`** contains "look-and-feel" information on how to display a **`Button`** on the Macintosh operating system.

Two problems arise from this approach. First, if we create new **`Button`** subclasses, we must create corresponding **`Win32Button`** and **`MacButton`** subclasses. For example, if we create class **`ImageButton`** (a **`Button`** with an overlapping **`Image`**) that extends class **`Button`**, we must create additional subclasses **`Win32ImageButton`** and **`MacImageButton`**. In fact, we must create **`Button`** subclasses for every operating system we wish to support, which increases development time. The second problem is that when a new operating system enters the market, we must create additional **`Button`** subclasses specific to that operating system.

The *Bridge design pattern* avoids these problems by separating an abstraction (e.g., a **`Button`**) and its implementations (e.g., **`Win32Button`**, **`MacButton`**, etc.) into different class hierarchies. For example, the Java AWT classes use the Bridge design pattern to enable designers to create AWT **`Button`** subclasses without needing to create corresponding subclasses for each operating system. Each AWT **`Button`** maintains a reference to a **`ButtonPeer`**, which is the superclass for platform-specific implementations, such as **`Win32ButtonPeer`**, **`MacButtonPeer`**, etc. When a programmer creates a **`Button`** object, class **`Button`** calls factory method **`createButton`** of class **`Toolkit`** to create the platform-specific **`ButtonPeer`** object. The **`Button`** object stores a reference to its **`ButtonPeer`**—this reference is the "bridge" in the Bridge design pattern. When the programmer invokes methods on the **`Button`** object, the **`Button`** object invokes the appropriate method on its **`ButtonPeer`** to fulfill the request. If a designer creates a **`Button`** subclass called **`ImageButton`**, the designer does not need to create a corresponding **`Win32ImageButton`** or **`MacImageButton`** with platform-specific image-drawing capabilities. An **`ImageButton`** "is a" **`Button`**. Therefore, when an **`ImageButton`** needs to display its image, the **`ImageButton`** uses its **`ButtonPeer`**'s **`Graphics`** object to render the image on each platform. This design pattern enables designers to create new cross-platform GUI components using a "bridge" to hide platform-specific details.

Portability Tip 13.2

Designers often use the Bridge design pattern to enhance the platform independence of their systems. This design pattern enables designers to create new cross-platform components using a "bridge" to hide platform-specific details.

Composite

Designers often organize components into hierarchical structures (e.g., a hierarchy of directories and files on a hard drive)—each node in the structure represents a component (e.g., a file or directory). Each node can contain references to other nodes. A node is called a *branch* if it contains a reference to one or more nodes (e.g., a directory containing files). A node is called a *leaf* if it does not contain a reference to another node (e.g., a file). Occasionally, a structure contains objects from several different classes (e.g., a directory can contain files and directories). When an object—called a *client*—wants to traverse the structure, the client must determine the particular class for each node. Making this determination can be time consuming, and the structure can become hard to maintain.

In the *Composite design pattern*, each component in a hierarchical structure implements the same interface or extends a common superclass. This polymorphism (introduced in Section 9.10) ensures that clients can traverse all elements—branch or leaf—uniformly in the structure. Using this pattern, a client traversing the structure does not have to determine each component type, because all components implement the same interface or extend the same superclass.

Java GUI components use the Composite design pattern. Consider the Swing component class **`JPanel`**, which extends class **`JComponent`**. Class **`JComponent`** extends class **`java.awt.Container`**, which extends class **`java.awt.Component`** (Fig. 13.22). Class **`Container`** provides method **`add`**, which appends a **`Component`** object (or **`Component`** subclass object) to that **`Container`** object. Therefore, a **`JPanel`** object may be added to any object of a **`Component`** subclass, and any object from a **`Component`** subclass may be added to that **`JPanel`** object. A **`JPanel`** object can contain any GUI component while remaining unaware of that component's specific type.

A client, such as a **`JPanel`** object, can traverse all components uniformly in the hierarchy. For example, if the **`JPanel`** object calls method **`repaint`** of superclass **`Container`**, method **`repaint`** displays the **`JPanel`** object and all components added to the **`JPanel`** object. Method **`repaint`** does not have to determine each component's type, because all components inherit from superclass **`Container`**, which contains method **`repaint`**.

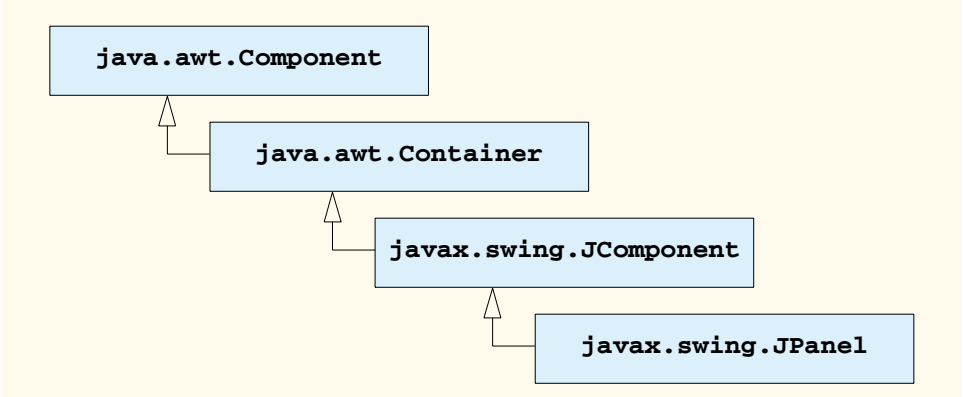


Fig. 13.22 Inheritance hierarchy for class **`JPanel`**.

13.18.3 Behavioral Design Patterns

In this section, we continue our discussion on behavioral design patterns. We discuss the Chain-of-Responsibility, Command, Observer, Strategy and Template Method design patterns.

Chain-of-Responsibility

In object-oriented systems, objects interact by sending messages to one another. Often, a system needs to determine at run time the object that will handle a particular message. For example, consider the design of a three-line office phone system. When a person calls the office, the first line handles the call—if the first line is busy, the second line handles the call, and if the second line is busy, the third line handles the call. If all lines in the system are busy, an automated speaker instructs that person to wait for the next available line—when a line becomes available, that line handles the call.

The *Chain-of-Responsibility design pattern* enables a system to determine at run time the object that will handle a message. This pattern allows an object to send a message to several objects in a *chain* of objects. Each object in the chain either may handle the message or pass the message to the next object in the chain. For instance, the first line in the phone system is the first object in the chain of responsibility, the second line is the second object, the third line is the third object, and the automated speaker is the fourth object. Note that this mechanism is not the final object in the chain—the next available line handles the message, and that line is the final object in the chain. The chain is created dynamically in response to the presence or absence of specific message handlers.

Several Java AWT GUI components use the Chain-of-Responsibility design pattern to handle certain events. For example, class **`java.awt.Button`** overrides method **`processEvent`** of class **`java.awt.Component`** to process **`AWTEvent`** objects. Method **`processEvent`** attempts to handle the **`AWTEvent`** upon receiving this event as an argument. If method **`processEvent`** determines that the **`AWTEvent`** is an **`ActionEvent`** (i.e., the **`Button`** has been pressed), the method handles the event by invoking method **`processActionEvent`**, which informs any **`ActionListener`** registered with the **`Button`** that the **`Button`** has been pressed. If method **`processEvent`** determines that the **`AWTEvent`** is not an **`ActionEvent`**, the method is unable to handle the event and passes the **`AWTEvent`** to method **`processEvent`** of superclass **`Component`** (the next object in the chain).

Command

Applications often provide users with several ways to perform a given task. For example, in a word processor there might be an **Edit** menu with menu items for cutting, copying and pasting text. There could also be a toolbar and/or a popup menu offering the same items. The functionality the application provides is the same in each case—the different interface components for invoking the functionality are provided for the user's convenience. However, the same GUI component instance (e.g., **`JButton`**) cannot be used for menus and toolbars and popup menus, so the developer must code the same functionality three times. If there were many such interface items, repeating this functionality would become tedious and error-prone.

The *Command design pattern* solves this problem by enabling developers to specify the desired functionality (e.g., copying text) once in a reusable object; that functionality can

then be added to a menu, toolbar, popup menu or other mechanisms. This design pattern is called Command because it defines a user command, or instruction. This pattern allows a designer to encapsulate a command, so that the command may be used among several objects.

Observer

Suppose we want to design a program for viewing bank account information. This system includes class **`BankStatementData`** to store data pertaining to bank statements, and classes **`TextDisplay`**, **`BarGraphDisplay`** and **`PieChartDisplay`** to display the data.[2] Figure 13.23 shows the design for our system. Class **`TextDisplay`** displays the data in text format, class **`BarGraphDisplay`** displays the data in bar-graph format and class **`PieChartDisplay`** displays the data as a pie chart. We want to design the system so that the **`BankStatementData`** object notifies the objects displaying the data of a change in the data. We also want to design the system to loosen *coupling*—the degree to which classes depend on each other in a system.

Software Engineering Observation 13.9

Loosely-coupled classes are easier to reuse and modify than are tightly-coupled classes, which depend heavily on each other. A modification in a class in a tightly-coupled system usually results in modifying other classes in that system. A modification to one of a group of loosely-coupled classes would require little or no modification to the other classes in the group.

The *Observer design pattern* is appropriate for systems like that of Fig. 13.23. This pattern promotes loose coupling between a *subject* object and *observer* objects—a subject notifies the observers when the subject changes state. When notified by the subject, the observers change in response to the change in the subject. In our example, the **`BankStatementData`** object is the subject, and the objects displaying the data are the observers. A subject can notify several observers; therefore, the subject contains a one-to-many relationship with the observers.

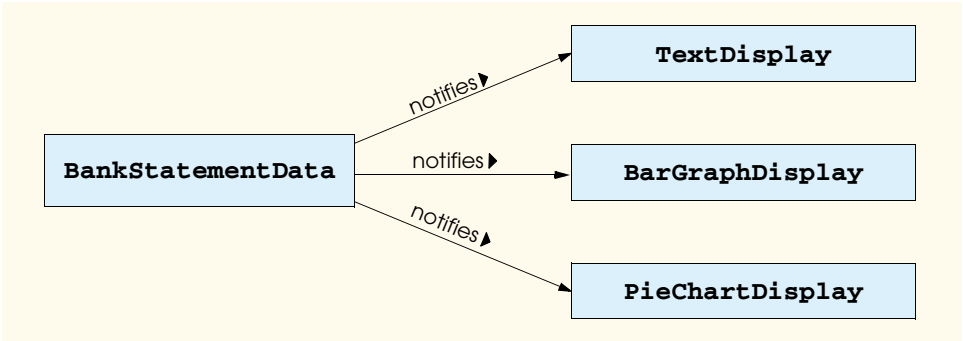


Fig. 13.23 Basis for the Observer design pattern.

2. This approach is the basis for the Model-View-Controller architecture pattern, discussed in Sections 13.17 and 17.11.

The Java API contains classes that use the Observer design pattern. Class ***java.util.Observable*** represents a subject. Class **Observable** provides method **addObserver**, which takes a ***java.util.Observer*** argument. Interface **Observer** allows the **Observable** object to notify the **Observer** when the **Observable** objects changes state. The **Observer** can be an instance of any class that implements interface **Observer**; because the **Observable** object invokes methods defined in interface **Observer**, the objects remain loosely coupled. If a developer changes the way in which a particular **Observer** responds to changes in the **Observable** object, the developer does not need to change the **Observable** object. The **Observable** object interacts with its **Observer**s only through interface **Observer**, which enables the loose coupling.

The optional elevator simulation case study in the "Thinking About Objects" sections uses the Observer design pattern to allow the **ElevatorModel** object (the subject) to notify the **ElevatorView** object (the observer) of changes in the **ElevatorModel**. The simulation does not use class **Observable** and interface **Observer** from the Java library—rather, it uses a custom interface **ElevatorModelListener** that provides functionality similar to that of interface **Observable**.

The Swing GUI components use the Observer design pattern. GUI components collaborate with their listeners to respond to user interactions. For example, an **ActionListener** observes state changes in a **JButton** (the subject) by registering to handle that **JButton**'s events. When pressed by the user, the **JButton** notifies its **ActionListener** objects (the observers) that the **JButton**'s state has changed (i.e., the **JButton** has been pressed).

Strategy

The *Strategy design pattern* is similar to the State design pattern (discussed in Section 9.24.3). We mentioned that the State design pattern contains a state object, which encapsulates the state of a context object. The Strategy design pattern contains a *strategy object*, which is analogous to the State design pattern's state object. The key difference between a state object and a strategy object is that the strategy object encapsulates an *algorithm* rather than state information.

For example, **java.awt.Container** components implement the Strategy design pattern using **LayoutManager**s (discussed in Section 12.14) as strategy objects. In package **java.awt**, classes **FlowLayout**, **BorderLayout** and **GridLayout** implement interface **LayoutManager**. Each class uses method **addLayoutComponent** to add GUI components to a **Container** object—however, each method uses a different algorithm to display these GUI components: a **FlowLayout** displays components in a left-to-right sequence; a **BorderLayout** displays components in five regions; and a **GridLayout** displays components in row-column format.

Class **Container** contains a reference to a **LayoutManager** object (the strategy object). Because an interface reference (i.e., the reference to the **LayoutManager** object) can hold references to objects of classes that implement that interface (i.e., the **FlowLayout**, **BorderLayout** or **GridLayout** objects), the **LayoutManager** object can reference a **FlowLayout**, **BorderLayout** or **GridLayout** at any one time. Class **Container** can change this reference through method **setLayout** to select different layouts at run time.

Class **FlowLayoutDemo** (Fig. 12.24) demonstrates the application of the Strategy pattern—line 16 declares a new **FlowLayout** object and line 19 invokes the **Con-**

tainer object's method **setLayout** to assign the **FlowLayout** object to the **Container** object. In this example, the **FlowLayout** provides the strategy for laying out the components.

Template Method

The *Template Method design pattern* also deals with algorithms. The Strategy design pattern allows several objects to contain distinct algorithms. However, the Template Method design pattern requires all objects to share a single algorithm defined by a superclass.

For example, consider the design of Fig. 13.23, which we mentioned in the Observer design pattern discussion. Objects of classes **TextDisplay**, **BarGraphDisplay** and **PieChartDisplay** use the same basic algorithm for acquiring and displaying the data—get all statements from the **BankStatementData** object, parse the statements then display the statements. The Template Method design pattern allows us to create an abstract superclass called **BankStatementDisplay** that provides the central algorithm for displaying the data. In this example, the algorithm comprises abstract methods **getData**, **parseData** and **displayData** comprise the algorithm. Classes **TextDisplay**, **BarGraphDisplay** and **PieChartDisplay** extend class **BankStatementDisplay** to inherit the algorithm, so each object can use the same algorithm. Each **BankStatementDisplay** subclass then overrides each method in a way specific to that subclass, because each class implements the algorithm differently from one another. For example, classes **TextDisplay**, **BarGraphDisplay** and **PieChartDisplay** might get and parse the data identically, but each class displays that data differently.

The Template Method design pattern allows us to extend the algorithm to other **BankStatementDisplay** subclasses—e.g., we could create classes, such as **LineGraphDisplay** or class **3DimensionalDisplay**, that use the same algorithm inherited from class **BankStatementDisplay**.

13.18.4 Conclusion

In this "Discovering Design Patterns" section, we discussed how Swing components take advantage of design patterns and how developers can integrate design patterns with GUI applications in Java. In "Discovering Design Patterns" Section 15.13, we discuss concurrency design patterns, which are particularly useful for developing multithreaded systems.

SUMMARY

- **JTextAreas** provide an area for manipulating multiple lines of text. Like class **JTextField**, class **JTextArea** inherits from **JTextComponent**.
- An external event (i.e., an event generated by a different GUI component) normally indicates when the text in a **JTextArea** should be processed.
- Scrollbars are provided for a **JTextArea** by attaching it to a **JScrollPane** object.
- Method **getSelectedText** returns the selected text from a **JTextArea**. Text is selected by dragging the mouse over the desired text to highlight it.
- Method **setText** sets the text in a **JTextArea**.
- To provide automatic word wrap in a **JTextArea**, attach it to a **JScrollPane** with horizontal scrollbar policy **JScrollPane.HORIZONTAL_SCROLLBAR_NEVER**.

- The horizontal and vertical scrollbar policies for a **JScrollPane** are set when a **JScrollPane** is constructed or with methods **setHorizontalScrollBarPolicy** and **setVerticalScrollBarPolicy** of class **JScrollPane**.
- A **JPanel** can be used as a dedicated drawing area that can receive mouse events and is often extended to create new GUI components.
- Swing components that inherit from class **JComponent** contain method **paintComponent**, which helps them draw properly in the context of a Swing GUI. **JComponent** method **paintComponent** should be overridden to call to the superclass version of **paintComponent** as the first statement in its body.
- Classes **JFrame** and **JApplet** are not subclasses of **JComponent**; therefore, they do not contain method **paintComponent** (they have method **paint**).
- Calling **repaint** for a Swing GUI component indicates that the component should be painted as soon as possible. The background of the GUI component is cleared only if the component is opaque. Most Swing components are transparent by default. **JComponent** method **setOpaque** can be passed a **boolean** argument indicating whether the component is opaque (**true**) or transparent (**false**). The GUI components of package **java.awt** are different from Swing components in that **repaint** results in a call to **Component** method **update** (which clears the component's background) and **update** calls method **paint** (rather than **paintComponent**).
- Method **setTitle** displays a **String** in a window's title bar.
- Drawing on any GUI component is performed with coordinates that are measured from the upper-left corner (0, 0) of that GUI component.
- Layout managers often use a GUI component's **getPreferredSize** method to determine the preferred width and height of a component when laying out that component as part of a GUI. If a new component has a preferred width and height, it should override method **getPreferredSize** to return that width and height as an object of class **Dimension** (package **java.awt**).
- The default size of a **JPanel** object is 0 pixels wide and 0 pixels tall.
- A mouse drag operation begins with a mouse-pressed event. All subsequent mouse drag events (for which **mouseDragged** will be called) are sent to the GUI component that received the original mouse-pressed event.
- **JSlider**s enable the user to select from a range of integer values. **JSlider**s can display major tick marks, minor tick marks and labels for the tick marks. They also support snap-to ticks, where positioning the thumb between two tick marks causes the thumb to *snap* to the closest tick mark.
- Most Swing GUI components support user interactions through both the mouse and the keyboard.
- If a **JSlider** has the focus, the left arrow key and right arrow key cause the thumb of the **JSlider** to decrease or increase by 1. The down arrow key and up arrow key also cause the thumb of the **JSlider** to decrease or increase by 1, respectively. The *PgDn key* (page down) and *PgUp key* (page up) cause the thumb of the **JSlider** to decrease or increase by block increments of one-tenth of the range of values, respectively. The *Home key* moves the thumb to the minimum value of the **JSlider** and the *End key* moves the thumb to the maximum value of the **JSlider**.
- **JSlider**s have either a horizontal orientation or a vertical orientation. For a horizontal **JSlider**, the minimum value is at the extreme left and the maximum value is at the extreme right of the **JSlider**. For a vertical **JSlider**, the minimum value is at the extreme bottom and the maximum value is at the extreme top of the **JSlider**. The relative position of the thumb indicates the current value of the **JSlider**.
- Method **setMajorTickSpacing** of class **JSlider** sets the spacing for tick marks on a **JSlider**. Method **setPaintTicks** with a **true** argument indicates that the tick marks should be displayed.

- **JSlider**s generate **ChangeEvents** (package **javax.swing.event**) when the user interacts with a **JSlider**. A **ChangeListener** (package **javax.swing.event**) defines method **stateChanged** that can respond to **ChangeEvent**s.
- Method **getValue** of class **JSlider** returns the current thumb position.
- A **JFrame** is a window with a title bar and a border. Class **JFrame** is a subclass of **java.awt.Frame** (which is a subclass of **java.awt.Window**).
- Class **JFrame** supports three operations when the user closes the window. By default, a **JFrame** is hidden when the user closes a window. This can be controlled with **JFrame** method **setDefaultCloseOperation**. Interface **WindowConstants** (package **javax.swing**) defines three constants for use with this method—**DISPOSE_ON_CLOSE**, **DO_NOTHING_ON_CLOSE** and **HIDE_ON_CLOSE** (the default).
- By default, a window is not displayed on the screen until its **setVisible** method is called with **true** as an argument. A window can also be displayed by calling its **show** method.
- A window's size should be set with a call to method **setSize**. The position of a window when it appears on the screen is specified with method **setLocation**.
- All windows generate window events when the user manipulates the window. Event listeners are registered for window events with method **addWindowListener** of class **Window**. The **WindowListener** interface provides seven methods for handling window events—**windowActivated** (called when the window is made active by clicking the window), **windowClosed** (called after the window is closed), **windowClosing** (called when the user initiates closing of the window), **windowDeactivated** (called when another window is made active), **windowIconified** (called when the user minimizes a window), **windowDeiconified** (called when a window is restored from being minimized) and **windowOpened** (called when a window is first displayed on the screen).
- The command-line arguments are automatically passed to **main** as the array of **String**s called **args**. The first argument after the application class name is the first **String** in the array **args**, and the length of the array is the total number of command-line arguments.
- *Menus* are an integral part of GUIs. Menus allow the user to perform actions without unnecessarily "cluttering" a graphical user interface with extra GUI components.
- In Swing GUIs, menus can be attached only to objects of the classes that provide method **setJMenuBar**. Two such classes are **JFrame** and **JApplet**.
- The classes used to define menus are **JMenuBar**, **JMenuItem**, **JMenu**, **JCheckBoxMenuItem** and class **JRadioButtonMenuItem**.
- A **JMenuBar** is a container for menus.
- A **JMenuItem** is a GUI component inside a menu that, when selected, causes an action to be performed. A **JMenuItem** can be used to initiate an action or it can be a *submenu* that provides more menu items from which the user can select.
- A **JMenu** contains menu items and can be added to a **JMenuBar** or to other **JMenu**s as submenus. When a menu is clicked, the menu expands to show its list of menu items.
- When a **JCheckBoxMenuItem** is selected, a check appears to the left of the menu item. When the **JCheckBoxMenuItem** is selected again, the check to the left of the menu item is removed.
- When multiple **JRadioButtonMenuItem**s are maintained as part of a **ButtonGroup**, only one item in the group can be selected at a given time. When a **JRadioButtonMenuItem** is selected, a filled circle appears to the left of the menu item. When another **JRadioButtonMenuItem** is selected, the filled circle to the left of the previously selected menu item is removed.
- **JFrame** method **setJMenuBar** attaches a menu bar to a **JFrame**.

- **AbstractButton** method **setMnemonic** (inherited into class **JMenu**) specifies the mnemonic for an **AbstractButton** object. Pressing the *Alt* key and the mnemonic performs the **AbstractButton**'s action (in the case of a menu, it opens the menu).
- Mnemonic characters are normally displayed with an underline.
- Dialog boxes can be either modal or modeless. A modal dialog box does not allow any other window in the application to be accessed until the dialog box is dismissed. A modeless dialog box allows other windows to be accessed while the dialog is displayed. By default, the dialogs displayed with class **JOptionPane** are modal dialogs. Class **JDialog** can be used to create your own modeless or modal dialogs.
- **JMenu** method **addSeparator** adds a separator line to a menu.
- Context-sensitive popup menus are created with class **JPopupMenu**. These menus provide options that are specific to the component for which the popup-trigger event was generated. On most systems, the popup-trigger event occurs when the user presses and releases the right mouse button.
- **MouseEvent** method **isPopupTrigger** returns **true** if the popup-trigger event occurred.
- Method **show** of class **JPopupMenu** displays a **JPopupMenu**. The first argument to method **show** specifies the origin component, whose position helps determine where the **JPopupMenu** will appear on the screen. The last two arguments are the x and y coordinates from the origin component's upper-left corner at which the **JPopupMenu** should appear.
- Class **UIManager** contains a **public static** inner class called **LookAndFeelInfo** that is used to maintain information about a look-and-feel.
- **UIManager static** method **getInstalledLookAndFeels** gets an array of **UIManager.LookAndFeelInfo** objects that describe the installed look-and-feels.
- **UIManager static** method **setLookAndFeel** changes the look-and-feel.
- **SwingUtilities static** method **updateComponentTreeUI** changes the look-and-feel of every component attached to its **Component** argument to the new look-and-feel.
- Many of today's applications use a multiple document interface (MDI) [i.e., a main window (often called the parent window) containing other windows (often called child windows)] to manage several open documents that are being processed in parallel.
- Swing's **JDesktopPane** and **JInternalFrame** classes provide support for creating multiple document interfaces.
- **BoxLayout** is a layout manager that allows GUI components to be arranged left-to-right or top-to-bottom in a container. Class **Box** defines a container with **BoxLayout** as its default layout manager and provides static methods to create a **Box** with a horizontal or vertical **BoxLayout**.
- **CardLayout** is a layout manager that stacks components like a deck of cards. Each container in the stack can use any layout manager. Only the container at the "top" of the deck is visible.
- **GridBagLayout** is a layout manager similar to **GridLayout**. Unlike with **GridLayout**, each component size can vary, and components can be added in any order.
- **Box static** method **createHorizontalBox** returns a **Box** container with a horizontal **BoxLayout**. **Box static** method **createVerticalBox** of class **Box** returns a **Box** container with a vertical **BoxLayout**.
- **Box static** method **createVerticalStrut** adds a *vertical strut* to a container. A vertical strut is an invisible GUI component that has a fixed pixel height and is used to guarantee a fixed amount of space between GUI components. Class **Box** also defines method **createHorizontalStrut** for horizontal **BoxLayout**s.
- **Box static** method **createHorizontalGlue** adds horizontal glue to a container. Horizontal glue is an invisible GUI component that can be used between fixed-size GUI components to

occupy additional space. Class **Box** also defines method **createVerticalGlue** for vertical **BoxLayout**s.

- **Box static** method **createRigidArea** adds a rigid area to a container. A rigid area is an invisible GUI component that always has a fixed pixel width and height.
- The **BoxLayout** constructor receives a reference to the container for which it controls the layout and a constant indicating whether the layout is horizontal (**BoxLayout.X_AXIS**) or vertical (**BoxLayout.Y_AXIS**).
- **CardLayout** methods **first**, **previous**, **next** and **last** are used to display a particular card. Method **first** displays the first card. Method **previous** displays the previous card. Method **next** displays the next card. Method **last** displays the last card.
- To use **GridBagLayout**, a **GridBagConstraints** object must be used to specify how a component is placed in a **GridBagLayout**.
- Method **setConstraints** of class **GridBagLayout** takes a **Component** argument and a **GridBagConstraints** argument and sets the constraints of the **Component**.

TERMINOLOGY

addSeparator method of class **JMenu**
addWindowListener method of **Window**
anchor variable of **GridBagConstraints**
automatic word wrap
Box class
BoxLayout layout manager
BoxLayout.X_AXIS
BoxLayout.Y_AXIS
CardLayout layout manager
ChangeEvent class
ChangeListener interface
child window
command-line arguments
context-sensitive popup menu
createHorizontalBox method of **Box**
createHorizontalGlue method of **Box**
createHorizontalStrut method of **Box**
createRigidArea method of **Box**
createVerticalBox method of **Box**
createVerticalGlue method of **Box**
createVerticalStrut method of **Box**
dedicated drawing area
Dimension class
dispose method of class **Window**
external event
fill variable of **GridBagConstraints**
first method of **CardLayout**
getClassName method
getInstalledLookAndFeels method
getMinimumSize method of **Component**
getPreferredSize method of **Component**
getSelectedText method
getValue method of class **JSlider**
GridBagConstraints class
GridBagConstraints.BOTH
GridBagConstraints.CENTER
GridBagConstraints.EAST
GridBagConstraints.HORIZONTAL
GridBagConstraints.NONE
GridBagConstraints.NORTH
GridBagConstraints.NORTHEAST
GridBagConstraints.NORTHWEST
GridBagConstraints.RELATIVE
GridBagConstraints.REMAINDER
GridBagConstraints.SOUTH
GridBagConstraints.SOUTHEAST
GridBagConstraints.SOUTHWEST
GridBagConstraints.VERTICAL
GridBagConstraints.WEST
GridBagLayout layout manager
gridheight variable
gridwidth variable
gridx variable of **GridBagConstraints**
gridy variable of **GridBagConstraints**
isPopupTrigger method of **MouseEvent**
JCheckBoxMenuItem class
JDesktopPane class
JInternalFrame class
JMenu class
JMenuBar class
JMenuItem class
JPopupMenu class
JRadioButtonMenuItem class
JSlider class
JTextArea class
JTextComponent class

labels for tick marks
last method of class **CardLayout**
major tick mark
menu
menu bar
menu item
metal look-and-feel
method **setMnemonic** of **AbstractButton**
minor tick mark
mnemonic
modal dialog
modeless dialog
Motif look-and-feel
multiple document interface (MDI)
next method of class **CardLayout**
paintComponent method of **JComponent**
parent window
pluggable look-and-feel (PLAF)
previous method of class **CardLayout**
scrollbar policies for a **JScrollPane**
setConstraints method
setDefaultCloseOperation method
setHorizontalScrollBarPolicy method
setJMenuBar method
setLookAndFeel method
setMajorTickSpacing method
setOpaque method of class **JComponent**
setPaintTicks method of class **JSlider**
setSelected method of **AbstractButton**
setTitle method of class **Frame**
setVerticalScrollBarPolicy method
show method of class **JPopupMenu**
snap-to ticks
submenu
super.paintComponent(g);
SwingConstants.HORIZONTAL
SwingConstants.VERTICAL
thumb of a **JSlider**
tick mark
UIManager class
UIManager.LookAndFeelInfo class
updateComponentTreeUI method
vertical strut
weightx variable of **GridBagConstraints**
weighty variable of **GridBagConstraints**
windowActivated method
windowClosed method
windowClosing method
WindowConstants.DISPOSE_ON_CLOSE
windowDeactivated method
windowDeiconified method
windowIconified method
WindowListener interface
windowOpened method
Windows look-and-feel

SELF-REVIEW EXERCISES

13.1 Fill in the blanks in each of the following statements:

a) The _____ class is used to create a menu object.
b) The _____ method places a separator bar in a menu.
c) Passing **false** to a **TextArea**'s _____ method prevents its text from being modified by the user.
d) **JSlider** events are handled by the _____ method of interface _____.
e) The **GridBagConstraints** instance variable _____ is set to **CENTER** by default.

13.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) When the programmer creates a **JFrame**, a minimum of one menu must be created and added to the **JFrame**.
b) The variable **fill** belongs to the **GridBagLayout** class.
c) **JFrame**s and applets cannot be used together in the same program.
d) The top-left corner of a **JFrame** or applet has a coordinate of (0, 0).
e) A **JTextArea**'s text is always read-only.
f) Class **JTextArea** is a direct subclass of class **Component**.
g) The default layout for a **Box** is **BoxLayout**.

13.3 Find the error(s) in each of the following and explain how to correct the error(s).

a)
```
JMenubar b;
```
b)
```
mySlider = JSlider( 1000, 222, 100, 450 );
```

c)
```
gbc.fill = GridBagConstraints.NORTHWEST;  // set fill
```
d)
```
// override to paint on a customized Swing component
public void paintcomponent( Graphics g )
{
   g.drawString( "HELLO", 50, 50 );
}
```
e)
```
// create a JFrame and display it
JFrame f = new JFrame( "A Window" );
f.setVisible( true );
```

ANSWERS TO SELF-REVIEW EXERCISES

13.1 a) **JMenu**. b) **addSeparator**. c) **setEditable**. d) **stateChanged**, **ChangeListener**. e) **anchor**.

13.2
a) False. A **JFrame** does not require any menus.
b) False. The variable **fill** belongs to the **GridBagConstraints** class.
c) False. They can be used together.
d) True.
e) False. **JTextArea**s are editable by default.
f) False. **JTextArea** derives from class **JTextComponent**.
g) True.

13.3
a) **JMenubar** should be **JMenuBar**.
b) The first argument to the constructor should be either **SwingConstants.HORIZONTAL** or **SwingConstants.VERTICAL**, and the **new** operator must be used after the **=** operator.
c) The constant should be either **BOTH**, **HORIZONTAL**, **VERTICAL** or **NONE**.
d) **paintcomponent** should be **paintComponent** and the method should call **super.paintComponent(g)** as its first statement.
e) The **JFrame**'s **setSize** method must also be called to determine the size of the window.

EXERCISES

13.4 Fill in the blanks in each of the following statements:
a) A dedicated drawing area can be defined as a subclass of _____.
b) A **JMenuItem** that is a **JMenu** is called a _____
c) Both **JTextField**s and **JTextArea**s inherit directly from class _____.
d) The _____ method attaches a **JMenuBar** to a **JFrame**.
e) Container class _____ has a default **BoxLayout**.
f) A _____ manages a set of child windows defined with class **JInternalFrame**.

13.5 State whether each of the following is *true* or *false*. If *false*, explain why.
a) Menus require a **JMenuBar** object so they can be attached to a **JFrame**.
b) A **JPanel** object is capable of receiving mouse events.
c) **CardLayout** is the default layout manager for a **JFrame**.
d) Method **setEditable** is a **JTextComponent** method.
e) The **GridBagLayout** layout manager implements **LayoutManager**.
f) **JPanel** objects are containers to which other GUI components can be attached.
g) Class **JFrame** inherits directly from class **Container**.
h) **JApplet**s can contain menus.

13.6 Find the error(s) in each of the following. Explain how to correct the error(s).
a)
```
x.add( new JMenuItem( "Submenu Color" ) ); // create submenu
```

b) `container.setLayout( m = new GridbagLayout() );`
c) `String s = JTextArea.getText();`

13.7 Write a program that displays a circle of random size and calculates and displays the area, radius, diameter and circumference. Use the following equations: *diameter* = 2 × *radius*, *area* = $\pi \times radius^2$, *circumference* = 2 × π × *radius*. Use the constant **`Math.PI`** for pi (π). All drawing should be done on a subclass of **`JPanel`**, and the results of the calculations should be displayed in a read-only **`JTextArea`**.

13.8 Enhance the program of Exercise 13.7 by allowing the user to alter the radius with a **`JSlider`**. The program should work for all radii in the range from 100 to 200. As the radius changes, the diameter, area and circumference should be updated and displayed. The initial radius should be 150. Use the equations of Exercise 13.7. All drawing should be done on a subclass of **`JPanel`**, and the results of the calculations should be displayed in a read-only **`JTextArea`**.

13.9 Explore the effects of varying the **`weightx`** and **`weighty`** values of the program of Fig. 13.20. What happens when a component has a nonzero weight, but is not allowed to fill the whole area (i.e., the **`fill`** value is not **`BOTH`**)?

13.10 Write a program that uses the **`paintComponent`** method to draw the current value of a **`JSlider`** on a subclass of **`JPanel`**. In addition, provide a **`JTextField`** where a specific value can be entered. The **`JTextField`** should display the current value of the **`JSlider`** at all times. A **`JLabel`** should be used to identify the **`JTextField`**. The **`JSlider`** methods **`setValue`** and **`getValue`** should be used. [Note: The **`setValue`** method is a **`public`** method that does not return a value and takes one integer argument—the **`JSlider`** value, which determines the position of the thumb.]

13.11 Modify the program of Fig. 13.16 to use a single **`JComboBox`** instead of the four separate **`JButton`**s. Each "card" should not be modified.

13.12 Modify the program of Fig. 13.16 by adding a minimum of two new "cards" to the deck.

13.13 Define a subclass of **`JPanel`** called **`MyColorChooser`** that provides three **`JSlider`** objects and three **`JTextField`** objects. Each **`JSlider`** represents the values from 0 to 255 for the red, green and blue parts of a color. Use the red, green and blue values as the arguments to the **`Color`** constructor to create a new **`Color`** object. Display the current value of each **`JSlider`** in the corresponding **`JTextField`**. When the user changes the value of the **`JSlider`**, the **`JTextField`** should be changed accordingly. Define class **`MyColorChooser`** so it can be reused in other applications or applets. Use your new GUI component as part of an applet that displays the current **`Color`** value by drawing a filled rectangle.

13.14 Modify the **`MyColorChooser`** class of Exercise 13.13 to allow the user to type an integer value into a **`JTextField`** to set the red, green or blue value. When the user presses *Enter* in the **`JTextField`**, the corresponding **`JSlider`** should be set to the appropriate value.

13.15 Modify the applet of Exercise 13.14 to draw the current color as a rectangle on an instance of a subclass of **`JPanel`** called **`DrawPanel`**. Class **`DrawPanel`** should provide its own **`paintComponent`** method to draw the rectangle and should provide *set* methods to set the red, green and blue values for the current color. When any *set* method is invoked for the class **`DrawPanel`**, the object should automatically **`repaint`** itself.

13.16 Modify the applet of Exercise 13.15 to allow the user to drag the mouse across the **`DrawPanel`** to draw a shape in the current color. Enable the user to choose what shape to draw.

13.17 Modify the program of Exercise 13.16 to enable the program to run as an application. The existing applet's code should be modified only by adding a **`main`** method to launch the application in its own **`JFrame`**. Provide the user with the ability to terminate the application by clicking the close

box on the window that is displayed and by selecting **`Exit`** from a **`File`** menu. Use the techniques shown in Fig. 13.9.

13.18 *(Complete Drawing Application)* Using the techniques developed in Exercise 12.27–Exercise 12.33 and Exercise 13.13–Exercise 13.17, create a complete drawing program that can execute as both an applet and an application. The program should use the GUI components of Chapter 12 and Chapter 13 to enable the user to select the shape, color and fill characteristics. Each shape should be stored in an array of **`MyShape`** objects, where **`MyShape`** is the superclass in your hierarchy of shape classes (see Exercise 9.28 and Exercise 9.29). Use a **`JDesktopPane`** and **`JInternalFrame`**s to allow the user to create multiple separate drawings in separate child windows. Create the user interface as a separate child window containing all the GUI components that allow the user to determine the characteristics of the shape to be drawn. The user can then click in any **`JInternalFrame`** to draw the shape.

13.19 A company pays its employees as managers (who receive a fixed weekly salary), hourly workers (who receive a fixed hourly wage for up to the first 40 hours they work and "time-and-a-half," i.e., 1.5 times their hourly wage, for overtime hours worked), commission workers (who receive $250 plus 5.7% of their gross weekly sales) or pieceworkers (who receive a fixed amount of money per item for each of the items they produce—each pieceworker in this company works on only one type of item). Write an application to compute the weekly pay for each employee. Each type of employee has its own pay code: Managers have paycode 1, hourly workers have code 2, commission workers have code 3 and pieceworkers have code 4. Use a **`switch`** to compute each employee's pay based on that employee's paycode. Use a **`CardLayout`** to display the appropriate GUI components that allow the user to enter the facts your program needs to calculate each employee's pay based on that employee's paycode.

14

Exception Handling

Objectives

- To understand exception and error handling.
- To be able to use **`try`** blocks to delineate code in which an exception may occur.
- To be able to **`throw`** exceptions.
- To use **`catch`** blocks to specify exception handlers.
- To use the **`finally`** block to release resources.
- To understand the Java exception hierarchy.
- To create programmer-defined exceptions.

It is common sense to take a method and try it. If it fails, admit it frankly and try another. But above all, try something.
Franklin Delano Roosevelt

O! throw away the worser part of it,
And live the purer with the other half.
William Shakespeare

If they're running and they don't look where they're going I have to come out from somewhere and catch them.
Jerome David Salinger

And oftentimes excusing of a fault
Doth make the fault the worse by the excuse.
William Shakespeare

I never forget a face, but in your case I'll make an exception.
Groucho (Julius Henry) Marx

Outline

14.1 Introduction
14.2 When Exception Handling Should Be Used
14.3 Other Error-Handling Techniques
14.4 Basics of Java Exception Handling
14.5 `try` Blocks
14.6 Throwing an Exception
14.7 Catching an Exception
14.8 Exception-Handling Example: Divide by Zero
14.9 Rethrowing an Exception
14.10 `throws` Clause
14.11 Constructors, Finalizers and Exception Handling
14.12 Exceptions and Inheritance
14.13 `finally` Block
14.14 Using `printStackTrace` and `getMessage`

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

14.1 Introduction

In this chapter, we introduce *exception handling*. An *exception* is an indication that a problem occurred during the program's execution. The extensibility of Java can increase the number and types of errors that can occur. Every new class can add its own error possibilities. The features presented here enable programmers to write clearer, more robust, more fault-tolerant programs. We also consider when exception handling should not be used.

The style and details of exception handling in Java as presented in this chapter are based in part on the work of Andrew Koenig and Bjarne Stroustrup as presented in their paper, "Exception Handling for C++ (revised)," published in the *Proceedings of the USENIX C++ Conference* held in San Francisco in April 1990. Their work forms the basis of C++ exception handling. Java's designers chose to implement an exception handling mechanism similar to that used in C++.

Error-handling code varies in nature and quantity among software systems depending on the application and whether the software is a product for release. Products tend to contain far more error-handling code than does "casual" software.

There are many popular means for dealing with errors. Most commonly, error-handling code is interspersed throughout a system's code. Errors are dealt with at the places in the code where the errors can occur. The advantage to this approach is that a programmer reading code can see the error processing in the immediate vicinity of the code and determine if the proper error checking has been implemented.

The problem with this scheme is that the code can become "polluted" with the error processing. It becomes more difficult for a programmer concerned with the application itself to read the code and determine if it is functioning correctly. This can make understanding and maintaining the application difficult.

Some common examples of exceptions are an out-of-bounds array subscript, arithmetic overflow (i.e., a value outside the representable range of values), division by zero, invalid method parameters and memory exhaustion.

Good Programming Practice 14.1

Using Java exception handling enables the programmer to remove the error-handling code from the "main line" of the program's execution. This improves program clarity and enhances modifiability.

Exception handling is provided to enable programs to catch and handle errors rather than letting them occur and suffering the consequences. Exception handling is designed for dealing with *synchronous errors* such as an attempt to divide by zero (that occurs as the program executes the divide instruction). Exception handling is not designed to deal with *asynchronous* events such as disk I/O completions, network message arrivals, mouse clicks, keystrokes and the like; these are best handled through other means, such as Java event listeners.

Java exception handling enables a program to catch all exceptions, all exceptions of a certain type or all exceptions of related types. This flexibility makes programs more robust by reducing the likelihood that programs will not process problems during program execution.

Exception handling is used in situations in which the system can recover from the malfunction that caused the exception. The recovery procedure is called an *exception handler*. The exception handler can be defined in the method that may cause an exception or in a calling method.

Software Engineering Observation 14.1

Use exceptions for malfunctions that must be processed in a different method from where they are detected. Use conventional error-handling techniques for local error processing in which a method is able to deal with its own exceptions.

Exception handling is designed to process exceptional conditions—problems that do not happen frequently, but *can* happen. It is possible that the exception-handling code may not be optimized to the same performance levels as other language elements.

Performance Tip 14.1

When an exception does not occur, little or no overhead is imposed by the presence of exception handling code. When exceptions happen, they do incur execution-time overhead.

Testing and Debugging Tip 14.1

Exception handling helps improve a program's fault tolerance.

Good Programming Practice 14.2

Using Java's standardized exception handling rather than having programmers use a diversity of "home-grown" techniques improves program clarity on large projects.

We will see that exceptions are objects of classes derived from superclass **`Exception`**. We will show how to deal with "uncaught" exceptions. We will consider how unexpected exceptions are handled by Java. We will show how related exception types can be represented by exception subclasses that are derived from a common exception superclass.

Exception handling can be viewed as another means of returning control from a method or exiting a block of code. Normally, when an exception occurs, the exception is

handled by a caller of the method generating the exception, by a caller of that caller, or however far back in the call stack it becomes necessary to go to find a handler for that exception.

Software Engineering Observation 14.2

Exception handling is particularly well-suited to systems of separately developed components. Such systems are typical of real-world software. Exception handling makes it easier to combine the components and have them work together effectively.

Software Engineering Observation 14.3

With other programming languages that do not support exception handling, programmers often delay writing error-processing code, and sometimes programmers simply forget to include it. This results in less-robust, and thus inferior, software products. Java forces the programmer to deal with exception handling from the inception of a project. Still, the programmer must put considerable effort into incorporating an exception-handling strategy into software projects.

Software Engineering Observation 14.4

It is best to incorporate your exception-handling strategy into a system from the inception of the design process. It is difficult to add effective exception handling after a system has been implemented.

14.2 When Exception Handling Should Be Used

Exception handling should be used

- to process exceptional situations where a method is unable to complete its task for reasons it cannot control,
- to process exceptions from program components that are not geared to handling those exceptions directly, or
- on large projects to handle exceptions in a uniform manner project wide.

Software Engineering Observation 14.5

The client of a library class will likely have unique error processing in mind for an exception generated in the library class. It is unlikely that a library class will perform error processing that would meet the unique needs of all clients. Exceptions are an appropriate means for dealing with errors produced by library classes.

14.3 Other Error-Handling Techniques

We have presented various ways of dealing with exceptional situations prior to this chapter. A program can ignore some exception types. This can be devastating for software products released to the general public, or for special-purpose software needed for mission-critical situations. But for software developed for your own purposes, it is common to ignore many kinds of errors. A program could be directed to abort upon encountering an exceptional situation. This prevents a program from running to completion and producing incorrect results. For many types of errors this is a good strategy. Such a strategy is inappropriate for mission-critical applications. Resource issues also are important here. If a program obtains a resource, the program should return that resource before program termination.

Common Programming Error 14.1

Aborting a program could leave a resource in a state in which other programs would not be able to acquire the resource; hence, we would have a so-called "resource leak."

Good Programming Practice 14.3

If your method is capable of handling a given type of exception, then handle it rather than passing the exception on to other regions of your program. This makes programs clearer.

Performance Tip 14.2

If an error can be processed locally instead of throwing an exception, do so. This will improve program execution speed. Exception handling is slow compared to local processing.

14.4 Basics of Java Exception Handling

In this section, we overview the Java exception-handling process. Throughout the chapter, we present detailed discussions of the steps discussed here.

Java exception handling is geared to situations in which the method that detects an error is unable to deal with it. Such a method will *throw an exception*. There is no guarantee that there will be "anything out there" (i.e., an *exception handler*—code that executes when the program detects an exception) to process that kind of exception. If there is, the exception will be *caught* and *handled*. The following *Testing and Debugging Tip* describes what happens if no appropriate exception handler can be found.

Testing and Debugging Tip 14.2

All Java applets and certain Java applications are GUI-based. Some Java applications are not GUI-based; these are often called command-line applications (or console applications). When an exception is not caught in a command-line application, the program terminates (i.e., Java exits) after the default exception handler runs. When an exception is not caught in an applet or a GUI-based application, the GUI remains displayed and the user can continue using the applet or application even after the default exception handler runs. However, the program may be in an inconsistent state and may produce incorrect results.

The programmer encloses in a ***`try`*** *block* the code that may generate an exception and any code that should not execute if an exception occurs. The **`try`** block is followed by zero or more ***`catch`*** *blocks*. Each **`catch`** block specifies the type of exception it can catch and contains an exception handler. After the last **`catch`** block, an optional **`finally`** block provides code that always executes, regardless of whether an exception occurs. As we will see, the **`finally`** block is an ideal location for code that releases resources to prevent "resource leaks." The **`try`** block must be followed by a **`catch`** block or a **`finally`** block.

When a method throws an exception, program control leaves the **`try`** block and continues execution at the first **`catch`** block. The program searches the **`catch`** blocks in order looking for an appropriate handler. (We will soon discuss what makes a handler "appropriate".) If the type of the thrown exception matches the parameter type in one of the **`catch`** blocks, the code for that **`catch`** block executes. If a **`try`** block completes successfully without throwing any exceptions, the program skips the exception handlers for that block and resumes execution after the last **`catch`** block. If a **`finally`** block appears after the last **`catch`** block, the **`finally`** block executes regardless of whether an exception occurs.

In a method definition, a ***`throws`*** *clause* specifies the exceptions the method throws. This clause appears after the parameter list and before the method body. The clause con-

tains a comma-separated list of potential exceptions the method will throw if a problem occurs while the method executes. Such exceptions may by thrown be statements in the method's body, or they may be thrown by methods called in the body. The point at which the **throw** occurs is called the *throw point*.

When an exception occurs, the block in which the exception occurred expires (terminates)—program control cannot return directly to the throw point. Java uses the *termination model of exception handling* rather than the *resumption model of exception handling*. In the resumption model, control would return to the point at which the exception occurred and resume execution.

When an exception occurs, it is possible to communicate information to the exception handler from the vicinity in which the exception occurred. That information is the type of thrown exception object or information harvested from the vicinity in which the exception occurred and placed into the thrown object.

14.5 `try` Blocks

An exception that occurs in a **try** block normally is caught by an exception handler specified by a **catch** block immediately following that **try** block as in

```
try {
    statements that may throw an exception
}
catch( ExceptionType exceptionReference ) {
    statements to process an exception
}
```

A **try** block can be followed by zero or more **catch** blocks. If a **try** block executes and no exceptions are thrown, all the exception handlers are skipped and control resumes with the first statement after the last exception handler. If a **finally** block (presented in Section 14.13) follows the last **catch** block, the code in the **finally** block executes regardless of whether an exception is thrown. Note that an exception handler cannot access objects defined in the corresponding **try** block, because the **try** block expires before the handler begins executing.

Common Programming Error 14.2

It is a syntax error to separate with other code the **catch** *handlers that correspond to a particular* **try** *block.*

14.6 Throwing an Exception

The ***throw*** statement is executed to indicate that an exception has occurred (i.e., a method could not complete successfully). This is called *throwing an exception*. A **throw** statement specifies an object to be thrown. The operand of a **throw** can be of any class derived from class **Throwable** (package **java.lang**) The two immediate subclasses of class **Throwable** are **Exception** and **Error**. **Error**s are particularly serious system problems that generally should not be caught. **Exception**s are caused by problems that should be caught and processed during program execution to make a program more robust. If the operand of the **throw** is an object of class **Exception**, it is called an *exception object*.

Testing and Debugging Tip 14.3

When **`toString`** *is invoked on any* **`Throwable`** *object, its resulting* **`String`** *includes the descriptive* **`String`** *that was supplied to the constructor, or simply the class name if no* **`String`** *was supplied.*

Testing and Debugging Tip 14.4

An object can be thrown without containing information about the problem that occurred. In this case, simple knowledge that an exception of a particular type occurred may provide sufficient information for the handler to process the problem correctly.

When an exception is thrown, control exits the current **`try`** block and proceeds to an appropriate **`catch`** handler (if one exists) after that **`try`** block. It is possible that the **`throw`** point could be in a deeply nested scope within a **`try`** block; control will still proceed to the **`catch`** handler. It is also possible that the **`throw`** point could be in a deeply nested method call; still, control will proceed to the **`catch`** handler.

A **`try`** block may appear to contain no error checking and include no **`throw`** statements, but methods called from the **`try`** block may throw exceptions. Also, statements in a **`try`** block that do not invoke methods may cause exceptions. For example, a statement that performs array subscripting on an array object throws an **`ArrayIndexOutOfBoundsException`** if the statement specifies an invalid array subscript. Any method call can invoke code that might **`throw`** an exception or call another method that throws an exception.

14.7 Catching an Exception

Exception handlers are contained in **`catch`** blocks. Each **`catch`** block starts with the keyword **`catch`** followed by parentheses containing a class name (specifying the type of exception to be caught) and a parameter name. The handler can reference the thrown object through this parameter. This is followed by a block delineating the exception-handling code. When a handler catches an exception, the code in the **`catch`** block executes.

Common Programming Error 14.3

Logic errors can occur if you assume that after an exception is processed, control will return to the first statement after the **`throw`***. Program control continues with the first statement after the* **`catch`** *handlers.*

Common Programming Error 14.4

Specifying a comma-separated list of **`catch`** *parameters is a syntax error. A* **`catch`** *can have only a single parameter.*

Common Programming Error 14.5

It is a syntax error to **`catch`** *the same type in two different* **`catch`** *blocks associated with a particular* **`try`** *block.*

A **`catch`** that catches a **`Throwable`** object

```
catch( Throwable throwable )
```

catches all exceptions and errors. Similarly, a **`catch`** that catches an **`Exception`** object

```
catch( Exception exception )
```

catches all exceptions. In general, programs do not define exception handlers for type Throwable, because **`Error`**s normally should not be caught in a program.

Common Programming Error 14.6

Placing **`catch(Exception exception)`** *before other* **`catch`** *blocks that catch specific types of exceptions would prevent those blocks from executing; an exception handler that catches type* **`Exception`** *must be placed last in the list of exception handlers following a* **`try`** *block, or a syntax error occurs.*

It is possible that a **`try`** block will not have a corresponding **`catch`** handler that matches a particular thrown object. This causes the search for a matching **`catch`** handler to continue in the next enclosing **`try`** block. As this process continues, eventually the program may determine that there is no handler on the execution stack that matches the type of the thrown object. In this case, a non-GUI-based application terminates—applets and GUI-based applications return to their regular event processing. Although applets and GUI-based applications continue to execute, they may execute incorrectly.

Software Engineering Observation 14.6

If you know that a method may throw an exception, include appropriate exception-handling code in your program. This will make your program more robust.

Good Programming Practice 14.4

Read the online API documentation for a method before using that method in a program. The documentation specifies the exceptions thrown by the method (if any) and indicates reasons why such exceptions may occur.

Good Programming Practice 14.5

Read the online API documentation for an exception class before writing exception-handling code for that type of exception. The documentation for an exception class typically contains potential reasons that such exceptions may occur during program execution.

It is possible that several exception handlers will provide an acceptable match to the type of the exception. This can happen for several reasons: There can be a "catch-all" handler **`catch( Exception exception )`** that will catch any exception. Also, inheritance relationships enable a subclass object to be caught either by a handler specifying the subclass type, or by handlers specifying the types of any of that class's superclasses. The first exception handler that matches the exception type executes—all other exception handlers for the corresponding **`try`** block are ignored.

Software Engineering Observation 14.7

If several handlers match the type of an exception, and if each of these handles the exception differently, then the order of the handlers will affect the manner in which the exception is handled.

Common Programming Error 14.7

It is a syntax error if a **`catch`** *that catches a superclass object is placed before a* **`catch`** *for that class's subclass types.*

Sometimes a program may process many closely related types of exceptions. Instead of providing separate **`catch`** handlers for each, a programmer can provide a single **`catch`** handler for a group of exceptions.

What happens when an exception occurs in an exception handler? The **try** block that noticed the exception expires before the exception handler begins running, so exceptions occurring in an exception handler are processed by **catch** handlers for an enclosing **try** block. The enclosing **try** block watches for errors occurring in the original **try** block's **catch** handlers. An enclosing **try** block is either a **try** block that contains a complete **try**/**catch** sequence or a **try** block in a calling method.

Exception handlers can be written a variety of ways. They can rethrow an exception (as we will see in Section 14.9). They can convert one type of exception into another by throwing a different type of exception. They can perform any necessary recovery and resume execution after the last exception handler. They can look at the situation causing the error, remove the cause of the error and retry by calling the original method that caused an exception. They can return a status value to their environment, etc.

It is not possible to return to the **throw** point by issuing a **return** statement in a **catch** handler. Such a **return** simply returns control to the method that called the method containing the **catch** block. Again, the **throw** point is in a block that has expired, so returning to that point via a **return** statement would not make sense.

Software Engineering Observation 14.8

Another reason not to use exceptions for conventional flow of control is that these "additional" exceptions can "get in the way" of genuine error-type exceptions. It becomes more difficult for the programmer to keep track of the larger number of exception cases. Exceptional situations should be rare, not commonplace.

Common Programming Error 14.8

*Assuming that an exception thrown from a **catch** handler will be processed by that handler or any other handler associated with the same **try** block can lead to logic errors.*

14.8 Exception-Handling Example: Divide by Zero

Now let us consider a simple example of exception handling. The application of Fig. 14.1 and Fig. 14.2 uses **try**, **throw** and **catch** to detect, indicate and handle exceptions. The application displays two **JTextField**s in which the user can type integers. When the user presses the *Enter* key in the second **JTextField**, the program calls method **actionPerformed** to read the two integers from the **JTextField**s and pass the integers to method **quotient**, which calculates the quotient of the two values and returns a **double** result. If the user types 0 in the second **JTextField**, the program uses an exception to indicate that the user is attempting to divide by zero. Also, if the user types a noninteger value in either **JTextField**, a **NumberFormatException** occurs. In prior examples that read numeric values from the user, we simply assumed that the user would input a proper integer value. However, users sometimes make mistakes. This program demonstrates how to catch the **NumberFormatException** that occurs when a program attempts to convert a **String** that does not represent an integer value to an **int** value with **Integer** method **parseInt**.

Before we discuss the program, consider the sample executions shown in the five output windows of Fig. 14.2. The first window shows a successful execution. The user typed the values 100 and 7. The third **JTextField** shows the result of the division performed by method **quotient**. In the second output window, the user entered the string "hello" in the second **JTextField**. When the user presses *Enter* in the second **JText-**

Field, an error-message dialog is displayed indicating that an integer must be entered. In the last two windows, a zero denominator is entered and the program detects the problem, throws an exception and issues an appropriate diagnostic message.

Now let's discuss the program beginning with class **DivideByZeroException** of Fig. 14.1. Java can test for division by zero when the values in the division are both integers. If Java discovers an attempt to divide by zero in integer arithmetic, Java throws an ***ArithmeticException***. However, our program performs a floating-point division of two integers by casting the first integer to a **double** before performing the calculation. Java allows floating-point division by zero. The result is positive or negative infinity. (Classes **Float** and **Double** of package **java.lang** each provide constants that represent these values.) Even though Java allows floating-point division by zero, we would like to use exception handling in this example to indicate to the user of our program that they are attempting to divide by zero.

As we will see, method **quotient** throws an exception when it receives zero as its second argument. A method can throw an exception of any existing type in the Java API or of a type specific to the program. In this example, we demonstrate defining a new exception type. Actually, we could use class **ArithmeticException** (package **java.lang**) with a customized error message in this program.

Good Programming Practice 14.6

*Associating each type of serious execution-time malfunction with an appropriately named **Exception** class improves program clarity.*

Software Engineering Observation 14.9

If possible, use an existing exception type, rather than creating a new class. The Java API contains many exception types that may be suitable for your program.

```
1  // Fig. 14.1: DivideByZeroException.java
2  // Definition of class DivideByZeroException.
3  // Used to throw an exception when a
4  // divide-by-zero is attempted.
5  public class DivideByZeroException extends ArithmeticException {
6
7     // no-argument constructor specifies default error message
8     public DivideByZeroException()
9     {
10       super( "Attempted to divide by zero" );
11    }
12
13    // constructor to allow customized error message
14    public DivideByZeroException( String message )
15    {
16       super( message );
17    }
18
19 }  // end class DivideByZeroException
```

Fig. 14.1 Exception class **DivideByZeroException**.

Class **DivideByZeroException** extends class **ArithmeticException**. We chose to extend class **ArithmeticException** because dividing by zero occurs during arithmetic. Like any other class, an exception class can contain instance variables and methods. A typical exception class contains only two constructors—one that takes no arguments and specifies a default exception message and one that receives a customized exception message as a **String**. The default constructor (lines 8–11) specifies the string **"Attempted to divide by zero"** as the exception message that indicates what went wrong. This string is passed to the superclass constructor to initialize the error message associated with the exception object. The other constructor (lines 14–17) passes its argument—a customized error-message string—to the superclass constructor.

Software Engineering Observation 14.10

When defining your own exception type, subclass an existing related exception type in the Java API. This requires you to investigate the existing exceptions in the Java API. If the existing types are not appropriate for subclassing, the new exception class should extend ***Exception*** *if the client of your code should be required to handle the exception, or should extend* ***RuntimeException*** *if the client of your code should have the option of ignoring the exception.*

Now consider the **DivideByZeroTest** application (Fig. 14.2). The application's constructor (lines 21–51) builds a graphical user interface with three **JLabel**s (all right aligned) and three **JTextField**s and registers the **DivideByZeroTest** object as the **ActionListener** for **JTextField inputField2**.

```
1  // Fig. 14.2: DivideByZeroTest.java
2  // A simple exception handling example.
3  // Checking for a divide-by-zero-error.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.text.DecimalFormat;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class DivideByZeroTest extends JFrame
14    implements ActionListener {
15
16    private JTextField inputField1, inputField2, outputField;
17    private int number1, number2;
18    private double result;
19
20    // set up GUI
21    public DivideByZeroTest()
22    {
23       super( "Demonstrating Exceptions" );
24
```

Fig. 14.2 A simple exception-handling example with divide by zero (part 1 of 3).

```
25          // get content pane and set its layout
26          Container container = getContentPane();
27          container.setLayout( new GridLayout( 3, 2 ) );
28
29          // set up label and inputField1
30          container.add(
31             new JLabel( "Enter numerator ", SwingConstants.RIGHT ) );
32          inputField1 = new JTextField( 10 );
33          container.add( inputField1 );
34
35          // set up label and inputField2; register listener
36          container.add(
37             new JLabel( "Enter denominator and press Enter ",
38                SwingConstants.RIGHT ) );
39          inputField2 = new JTextField( 10 );
40          container.add( inputField2 );
41          inputField2.addActionListener( this );
42
43          // set up label and outputField
44          container.add(
45             new JLabel( "RESULT ", SwingConstants.RIGHT ) );
46          outputField = new JTextField();
47          container.add( outputField );
48
49          setSize( 425, 100 );
50          setVisible( true );
51       }
52
53       // process GUI events
54       public void actionPerformed( ActionEvent event )
55       {
56          DecimalFormat precision3 = new DecimalFormat( "0.000" );
57
58          outputField.setText( "" );    // clear outputField
59
60          // read two numbers and calculate quotient
61          try {
62             number1 = Integer.parseInt( inputField1.getText() );
63             number2 = Integer.parseInt( inputField2.getText() );
64
65             result = quotient( number1, number2 );
66             outputField.setText( precision3.format( result ) );
67          }
68
69          // process improperly formatted input
70          catch ( NumberFormatException numberFormatException ) {
71             JOptionPane.showMessageDialog( this,
72                "You must enter two integers",
73                "Invalid Number Format",
74                JOptionPane.ERROR_MESSAGE );
75          }
76
```

Fig. 14.2 A simple exception-handling example with divide by zero (part 2 of 3).

```
77          // process attempts to divide by zero
78          catch ( ArithmeticException arithmeticException ) {
79             JOptionPane.showMessageDialog( this,
80                arithmeticException.toString(),
81                "Arithmetic Exception",
82                JOptionPane.ERROR_MESSAGE );
83          }
84       }
85
86       // method quotient demonstrated throwing an exception
87       // when a divide-by-zero error occurs
88       public double quotient( int numerator, int denominator )
89          throws DivideByZeroException
90       {
91          if ( denominator == 0 )
92             throw new DivideByZeroException();
93
94          return ( double ) numerator / denominator;
95       }
96
97       // execute application
98       public static void main( String args[] )
99       {
100         DivideByZeroTest application = new DivideByZeroTest();
101
102         application.setDefaultCloseOperation(
103            JFrame.EXIT_ON_CLOSE );
104      }
105
106   }  // end class DivideByZeroTest
```

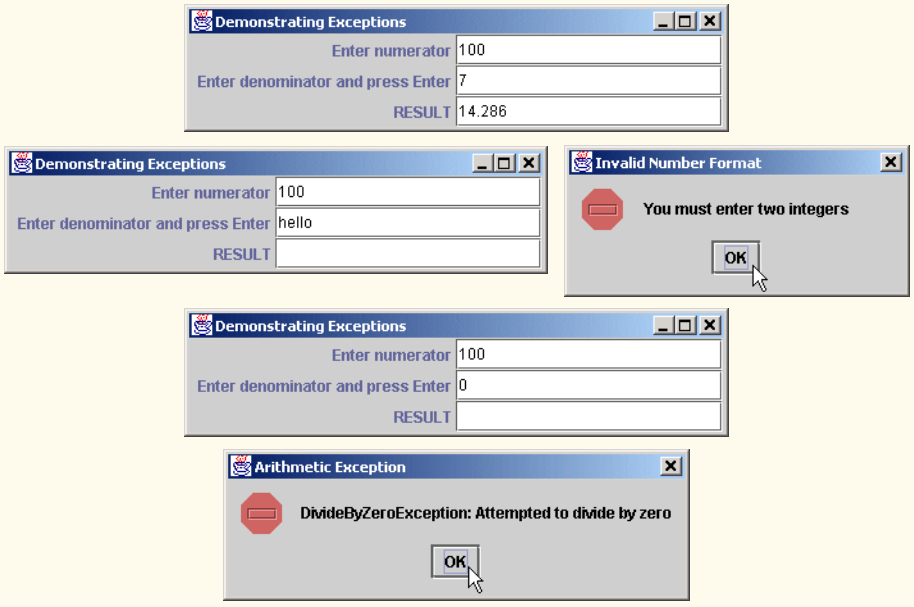


Fig. 14.2 A simple exception-handling example with divide by zero (part 3 of 3).

When the user inputs the denominator and presses the *Enter* key, the program calls method **actionPerformed** (lines 54–84). Next, method **actionPerformed** proceeds with a **try** block (lines 61–67), which encloses the code that may **throw** an exception and any code that should not be executed if an exception occurs. The statements that read the integers from the **JTextField**s (lines 62–63) each use method **Integer.parseInt** to convert **String**s to **int** values. Method **parseInt** throws a **NumberFormatException** if its **String** argument is not a valid integer. The division that can cause the divide-by-zero error is not performed explicitly in the **try** block. Rather, the call to method **quotient** (line 65) invokes the code that attempts the division. Method **quotient** (lines 89–96) **throw**s the **DivideByZeroException** object, as we will see momentarily. In general, errors may surface through explicitly mentioned code in a **try** block, through calls to a method or even through deeply nested method calls initiated by code in a **try** block.

The **try** block in this example is followed by two **catch** blocks—lines 70–75 contain the exception handler for the **NumberFormatException** and lines 78–83 contain the exception handler for the **DivideByZeroException**. In general, when the program detects an exception while executing a **try** block, the program catches the exception in a **catch** block that specifies an appropriate exception type (i.e., the type in the **catch** matches the thrown exception type exactly or is a superclass of the thrown exception type). In Fig. 14.2, the first **catch** block specifies that it will catch exception objects of type **NumberFormatException** (this type matches the exception object type thrown in method **Integer.parseInt**) and the second **catch** block specifies that it will catch exception objects of type **ArithmeticException** (this type is a superclass of the exception object type thrown in method **quotient**). Only the matching **catch** handler executes when an exception occurs. Both our exception handlers simply display an error-message dialog, but exception handlers can be more elaborate than this. After executing an exception handler, program control proceeds to the first statement after the last **catch** block (or in the **finally** block, if one is present).

If the code in the **try** block does not **throw** an exception, then the **catch** handlers are skipped and execution resumes with the first line of code after the **catch** handlers (or in the **finally** block, if one is present). In Fig. 14.2, method **actionPerformed** simply returns, but the program could continue executing more statements after the **catch** blocks.

Testing and Debugging Tip 14.5

With exception handling, a program can continue executing after dealing with a problem. This helps ensure robust applications that contribute to what is called mission-critical computing or business-critical computing.

Now let us examine method **quotient** (lines 89–96). When the **if** structure determines that **denominator** is zero, the body of the **if** executes a **throw** statement that creates and **throw**s a new **DivideByZeroException** object. This object will be caught by the **catch** block (lines 78–83) specifying type **ArithmeticException** after the **try** block. The **catch** block specifies parameter name **arithmeticException** to receive the thrown exception object. The **ArithmeticException** handler converts the exception to a **String** via **toString** and passes this **String** as the message to display in an error-message dialog.

If **denominator** is not zero, **quotient** does not throw an exception. Rather, **quotient** performs the division and returns the result of the division to the point of invocation

of method **quotient** in the **try** block (line 65). Line 66 displays the result of the calculation in the third **JTextField**. In this case, the **try** block completes successfully, so the program skips the **catch** blocks and the **actionPerformed** method completes execution normally.

Note that when **quotient** throws the **DivideByZeroException**, **quotient**'s block expires (i.e., the method terminates). This would cause any of its local variables to be destroyed—objects that were referenced by local variables in the block would have their reference counts decremented accordingly (and are possibly marked for garbage collection). Also, the **try** block from which the method was called expires before line 66 can execute. Here, too, if there were local variables created in the **try** block prior to the exception being thrown, these variables would be destroyed.

If a **NumberFormatException** is generated by lines 62–63, the **try** block expires and execution continues with the exception handler at line 70, which displays an error message to tell the user to input integers. Then the **actionPerformed** method continues with the next valid statement after the **catch** blocks (i.e., the method terminates in this example).

14.9 Rethrowing an Exception

It is possible that the **catch** handler that catches an exception may decide it cannot process the exception, or it may want to let some other **catch** handler handle the exception. In this case, the handler that received the exception can rethrow the exception with the statement

```
throw exceptionReference;
```

where *exceptionReference* is the parameter name for the exception in the **catch** handler. Such a **throw** rethrows the exception to the next enclosing **try** block.

Even if a handler can process an exception, and regardless of whether it does any processing on that exception, the handler still can rethrow the exception for further processing outside the handler. A rethrown exception is detected by the next enclosing **try** block and is handled by an exception handler listed after that enclosing **try** block.

14.10 throws Clause

A **throws** clause lists the exceptions that can be thrown by a method as in

```
int functionName( parameterList )
   throws ExceptionType1, ExceptionType2, ExceptionType3, ...
{
   // method body
}
```

The types of exceptions that are thrown by a method are specified in the method definition with a comma-separated list in the **throws** clause. A method can **throw** objects of the indicated classes, or it can **throw** objects of their subclasses.

Some exceptions can occur at any point during the execution of the program. Many of these exceptions can be avoided by coding properly. These are run-time exceptions, and they derive from class ***RuntimeException***. For example, if your program attempts to access an out-of-range array subscript, an exception of type **ArrayIndexOutOfBoundsException** (derived from **RuntimeException**) occurs. Your program clearly can avoid such a problem; hence, it is a run-time exception.

Another run-time exception occurs when your program creates an object reference, but has not yet created an object and assigned it to the reference. Attempting to use such a **`null`** reference causes a **`NullPointerException`** to be thrown. Clearly, your program can avoid this circumstance; hence, it is a run-time exception. Another run-time exception is an invalid cast, which throws a **`ClassCastException`**.

There are a variety of exceptions that are not **`RuntimeException`**s. Two of the most common are **`InterruptedException`**s (see Chapter 15, "Multithreading") and **`IOException`**s (see Chapter 16, "Files and Streams").

Not all errors and exceptions that can be thrown from a method are required to be listed in the **`throws`** clause. **`Error`**s do not need to be listed, nor do **`RuntimeException`**s (avoidable exceptions). **`Error`**s are serious system problems that can occur almost anywhere, and most programs will not be able to recover from them. Methods should process **`RuntimeException`**s caught in their bodies directly rather than passing them on to other program components. If a method throws any non-**`RuntimeException`**s, it *must* specify those exception types in its **`throws`** clause.

Software Engineering Observation 14.11

*If a non-**`RuntimeException`** is thrown by a method, or if that method calls methods that throw non-**`RuntimeException`**s, each of those exceptions must be declared in the **`throws`** clause of that method or caught in a **`try/catch`** in that method.*

Java distinguishes *checked* **`Exception`***s* versus *unchecked* ***`RuntimeExceptions`*** and **`Error`**s. A method's checked exceptions need to be listed in that method's **`throws`** clause. **`Error`**s and **`RuntimeException`**s can be thrown from almost any method, so it would be cumbersome for programmers to be required to list them for every method definition. Such exceptions and errors are not required to be listed in a method's **`throw`**s clause and, hence, are said to be "unchecked" by the compiler. All non-**`RuntimeException`**s a method can **`throw`** must be listed in that method's **`throws`** clause and, hence, are said to be "checked" by the compiler. If a non-**`RuntimeException`** is not listed in the throws clause, the compiler will issue an error message indicating that the exception must be caught (with a **`try`**/**`catch`** in the body of the method) or declared (with a **`throws`** clause).

Common Programming Error 14.9

*It is a syntax error if a method throws a checked exception not in that method's **`throws`** clause.*

Common Programming Error 14.10

*Attempting to throw a checked exception from a method that has no **`throws`** clause is a syntax error.*

Software Engineering Observation 14.12

*If your method calls other methods that explicitly **`throw`** checked exceptions, those exceptions must be listed in the **`throws`** clause of your method, unless your method catches those exceptions. This is Java's "**`catch`**-or-declare" requirement.*

Common Programming Error 14.11

*If a subclass method overrides a superclass method, it is an error for the subclass method to list more exceptions in its **`throws`** list than the overridden superclass method does. A subclass's **`throws`** list can contain a subset of a superclass's **`throws`** list.*

Java's ***catch**-or-declare requirement* demands that the programmer either **catch** each checked exception or place it in the **throws** clause of a method. Of course, placing a checked exception in the **throws** clause would force other methods to process the checked exception as well. If a programmer feels a particular checked exception is unlikely to occur, the programmer might elect to catch that checked exception and do nothing with it to avoid being forced to deal with it later. This can of course come back to haunt you, because as a program evolves, it may become important to deal with this checked exception.

Testing and Debugging Tip 14.6

*Do not try to circumvent Java's **catch**-or-declare requirement by simply catching exceptions and doing nothing with them. Exceptions are generally of a serious enough nature that they need to be processed rather than suppressed.*

Testing and Debugging Tip 14.7

*The Java compiler, through the **throws** clause used with exception handling, forces programmers to process the exceptions that can be thrown from each method a program calls. This helps avoid bugs that arise in programs when programmers ignore the fact that problems occur and make no provisions for these problems.*

Software Engineering Observation 14.13

*Subclass methods that do not override their corresponding superclass methods exhibit the same exception-handling behavior of the inherited superclass methods. The **throws** clause of a subclass method that overrides a superclass method may contain the same list of exceptions as the overridden superclass method or a subset of that list.*

Common Programming Error 14.12

*The Java compiler requires that a method either catch any checked exceptions thrown in the method (either directly from the method's body or indirectly through called methods) or declare checked **Exception**s the method can **throw** to other methods; otherwise, the Java compiler issues a syntax error.*

Testing and Debugging Tip 14.8

*Suppose a method **throw**s all subclasses of a particular exception superclass. You may be tempted to list only the superclass in the **throws** clause. Instead, explicitly list all the subclasses. This focuses the programmer's attention on the specific **Exception**s that may occur and will often help avoid bugs caused by performing general processing for a category of exception types.*

Figure 14.3–Fig. 14.8 list many of Java's **Error**s and **Exception**s hierarchically for the packages **java.lang**, **java.util**, **java.io**, **java.awt** and **java.net**. In these tables, a class indented under another class is a subclass. The exception and error classes for the other packages of the Java API can be found in the Java online documentation. The online documentation for each method in the API specifies whether that method throws exceptions and what the exceptions are that can be thrown. We show a portion of Java's **Error** hierarchy in Fig. 14.3. Most Java programmers ignore **Error**s. They are serious but rare events.

Figure 14.4 is particularly important because it lists many of Java's **RuntimeException**s. Although Java programmers are not required to declare these exceptions in **throws** clauses, these are the exceptions that commonly will be caught and handled in Java applications.

The `java.lang` package errors

`Error` (all in **`java.lang`** except for **`AWTError`**, which is in **`java.awt`**)

- **`LinkageError`**
  - **`ClassCircularityError`**
  - **`ClassFormatError`**
  - **`ExceptionInInitializerError`**
  - **`IncompatibleClassChangeError`**
    - **`AbstractMethodError`**
    - **`IllegalAccessError`**
    - **`InstantiationError`**
    - **`NoSuchFieldError`**
    - **`NoSuchMethodError`**
  - **`NoClassDefFoundError`**
  - **`UnsatisfiedLinkError`**
  - **`VerifyError`**
- **`ThreadDeath`**
- **`VirtualMachineError (Abstract class)`**
  - **`InternalError`**
  - **`OutOfMemoryError`**
  - **`StackOverflowError`**
  - **`UnknownError`**
- **`AWTError`** (package **`java.awt`**)

Fig. 14.3 The **`java.lang`** package errors .

The `java.lang` package exceptions

`Exception`

- **`ClassNotFoundException`**
- **`CloneNotSupportedException`**
- **`IllegalAccessException`**
- **`InstantiationException`**
- **`InterruptedException`**
- **`NoSuchFieldException`**
- **`NoSuchMethodException`**

Fig. 14.4 The **`java.lang`** package exceptions (part 1 of 2).

The `java.lang` package exceptions

```
RuntimeException
   ArithmeticException
   ArrayStoreException
   ClassCastException
   IllegalArgumentException
      IllegalThreadStateException
      NumberFormatException
   IllegalMonitorStateException
   IllegalStateException
   IndexOutOfBoundsException
      ArrayIndexOutOfBoundsException
      StringIndexOutOfBoundsException
   NegativeArraySizeException
   NullPointerException
   SecurityException
```

Fig. 14.4 The `java.lang` package exceptions (part 2 of 2).

Figure 14.5 lists Java's other three **`RuntimeException`**s data types. We will encounter these exceptions in Chapter 20 when we study the **`Vector`** class. A **`Vector`** is a dynamic array that can grow and shrink to accommodate a program's varying storage requirements.

Figure 14.6 lists Java's **`IOException`**s. These are all checked exceptions that can occur during input/output and file processing.

Figure 14.7 lists the **`java.awt`** package's only checked **`Exception`**, the **`AWTException`**. This is a checked exception that is thrown by various abstract windowing toolkit methods.

The `java.util` package exceptions

```
Exception
   RuntimeException
      EmptyStackException
      MissingResourceException
      NoSuchElementException
   TooManyListenersException
```

Fig. 14.5 The `java.util` package exceptions.

The `java.io` package exceptions

```
Exception
    IOException
        CharConversionException
        EOFException
        FileNotFoundException
        InterruptedIOException
        ObjectStreamException
            InvalidClassException
            InvalidObjectException
            NotActiveException
            NotSerializableException
            OptionalDataException
            StreamCorruptedException
            WriteAbortedException
        SyncFailedException
        UnsupportedCodingException
        UTFDataFormatException
```

Fig. 14.6 The `java.io` package exceptions .

The `java.awt` package exceptions

```
Exception
    AWTException
    RuntimeException
        IllegalStateException
            IllegalComponentStateException
```

Fig. 14.7 The `java.awt` package exceptions .

Figure 14.8 lists the **`IOException`**s of the **`java.net`** package. These are all checked **`Exception`**s that indicate various networking problems.

Most packages in the Java API define **`Exception`**s and **`Error`**s specific to the package. For a complete list of these types, see the online API documentation for the package.

The `java.net` package exceptions

```
Exception
   IOException
      BindException
      MalformedURLException
      ProtocolException
      SocketException
         ConnectException
         NoRouteToHostException
      UnknownHostException
      UnknownServiceException
```

Fig. 14.8 The `java.net` package exceptions.

14.11 Constructors, Finalizers and Exception Handling

First, let us deal with an issue we have mentioned, but that has yet to be resolved satisfactorily. What happens when an error is detected in a constructor? The problem is that a constructor cannot return a value, so how do we let the program know that an object has not been constructed properly? One scheme is to return the improperly constructed object and hope that anyone using the object would perform appropriate tests to determine that the object is in fact bad. However, this directly contradicts discussions in Chapter 8 in which we indicated that you should maintain an object in a consistent state at all times. Another scheme is to set some instance variable with an error indicator outside the constructor, but this is a poor programming practice. In Java, the typical (and proper) mechanism is to throw an exception from the constructor to the code creating the object. The thrown object contains the information about the failed constructor call and the caller is responsible for handling the failure.

When an exception occurs in a constructor, other objects created by that constructor are marked for eventual garbage collection. Before each object is garbage collected, its **`finalize`** method will be called.

14.12 Exceptions and Inheritance

Various exception classes can be derived from a common superclass. If a **`catch`** is written to catch exception objects of a superclass type, it can also catch all objects of subclasses of that superclass. This can allow for polymorphic processing of related exceptions.

Using inheritance with exceptions enables an exception handler to catch related errors with a concise notation. One could certainly catch each subclass exception object individually if those exceptions require different processing, but it is more concise to catch the superclass exception object. Of course, this makes sense only if the handling behavior would be the same for all subclasses. Otherwise, catch each subclass exception individually.

Testing and Debugging Tip 14.9

Catching subclass exception objects individually is subject to error if the programmer forgets to test for one or more of the subclass types explicitly; catching the superclass guarantees that objects of all subclasses will be caught. Often, a catch of the superclass type follows all other subclass exception handlers to ensure that all exceptions are processed properly.

14.13 `finally` Block

Programs that obtain certain types of resources must return those resources to the system explicitly to avoid so-called *resource leaks*. In programming languages like C and C++, the most common kind of resource leak is a memory leak. Java performs automatic garbage collection of memory no longer used by programs, thus avoiding most memory leaks. However, other types of resource leaks can occur in Java.

Software Engineering Observation 14.14

*A **`finally`** block typically contains code to release resources acquired in its corresponding **`try`** block; this is an effective way to eliminate resource leaks. For example, the **`finally`** block should close any files opened in the **`try`** block.*

Testing and Debugging Tip 14.10

Actually, Java does not eliminate memory leaks completely. There is a subtle issue here. Java will not garbage collect an object until there are no more references to the object. Thus, memory leaks can occur, but only if programmers erroneously keep references to unwanted objects. Most memory leak problems are solved by Java's garbage collection.

The **`finally`** block is optional. If it is present, it is placed after the last of a **`try`** block's **`catch`** blocks, as follows:

```
try {
   statements
   resource-acquisition statements
}
catch ( AKindOfException exception1 ) {
   exception-handling statements
}
catch ( AnotherKindOfException exception2 ) {
   exception-handling statements
}
finally {
   statements
   resource-release statements
}
```

Java guarantees that a **`finally`** block (if one is present) will execute regardless of whether any exception is thrown in the corresponding **`try`** block or any of its corresponding **`catch`** blocks. Java also guarantees that a **`finally`** block (if one is present) will execute if a **`try`** block exits via a **`return`**, **`break`** or **`continue`** statement.

Resource-release code is placed in a **`finally`** block. Suppose a resource is allocated in a **`try`** block. If no exception occurs, the **`catch`** handlers are skipped and control proceeds to the **`finally`** block, which frees the resource. Control then proceeds to the first statement after the **`finally`** block.

If an exception occurs, the program skips the rest of the **try** block. If the program catches the exception in one of the **catch** handlers, the program processes the exception. Then the **finally** block releases the resource, and control then proceeds to the first statement after the **finally** block.

If an exception that occurs in the **try** block cannot be caught by one of the **catch** handlers, the program skips the rest of the **try** block and control proceeds to the **finally** block, which releases the resource. Then the program passes the exception up the call chain until some calling method chooses to **catch** it. If no method chooses to deal with it, a non-GUI-based application terminates.

If a **catch** handler throws an exception, the **finally** block still executes. Then the exception is passed up the call chain for a calling method to **catch** and handle.

The Java application of Fig. 14.9 demonstrates that the **finally** block (if one is present) executes even if an exception is not thrown in the corresponding **try** block. The program contains methods **main** (lines 7–21), **throwException** (lines 24–50) and **doesNotThrowException** (lines 53–75). Methods **throwException** and **doesNotThrowException** are declared **static** so **main** (another **static** method) can call them directly.

Method **main** begins executing, enters its **try** block and immediately calls **throwException** (line 11). Method **throwException** throws an **Exception** (line 29), catches it (line 33) and rethrows it (line 37). The rethrown exception will be handled in **main**, but first the **finally** block (lines 44–47) executes. Method **main** detects the rethrown exception in the **try** block in **main** (lines 10–12) and handles it by the **catch** block (lines 15–18). Next, **main** calls method **doesNotThrowException** (line 20). No exception is thrown in **doesNotThrowException**'s **try** block, so the program skips the **catch** block (lines 61–64), but the **finally** block (lines 68–61) nevertheless executes. Control proceeds to the statement after the **finally** block. Then control returns to **main** and the program terminates.

```
1  // Fig. 14.9: UsingExceptions.java
2  // Demonstration of the try-catch-finally
3  // exception handling mechanism.
4  public class UsingExceptions {
5
6     // execute application
7     public static void main( String args[] )
8     {
9        // call method throwException
10       try {
11          throwException();
12       }
13
14       // catch Exceptions thrown by method throwException
15       catch ( Exception exception )
16       {
17          System.err.println( "Exception handled in main" );
18       }
19
```

Fig. 14.9 Demonstration of the **try-catch-finally** exception-handling mechanism (part 1 of 3).

```
20          doesNotThrowException();
21       }
22
23       // demonstrate try/catch/finally
24       public static void throwException() throws Exception
25       {
26          // throw an exception and immediately catch it
27          try {
28             System.out.println( "Method throwException" );
29             throw new Exception();  // generate exception
30          }
31
32          // catch exception thrown in try block
33          catch ( Exception exception )
34          {
35             System.err.println(
36                "Exception handled in method throwException" );
37             throw exception;  // rethrow for further processing
38
39             // any code here would not be reached
40          }
41
42          // this block executes regardless of what occurs in
43          // try/catch
44          finally {
45             System.err.println(
46                "Finally executed in throwException" );
47          }
48
49          // any code here would not be reached
50       }
51
52       // demonstrate finally when no exception occurs
53       public static void doesNotThrowException()
54       {
55          // try block does not throw an exception
56          try {
57             System.out.println( "Method doesNotThrowException" );
58          }
59
60          // catch does not execute, because no exception thrown
61          catch( Exception exception )
62          {
63             System.err.println( exception.toString() );
64          }
65
66          // this block executes regardless of what occurs in
67          // try/catch
68          finally {
69             System.err.println(
70                "Finally executed in doesNotThrowException" );
71          }
```

Fig. 14.9 Demonstration of the **`try-catch-finally`** exception-handling mechanism (part 2 of 3).

```
72
73          System.out.println(
74             "End of method doesNotThrowException" );
75       }
76
77    }  // end class UsingExceptions
```

```
Method throwException
Exception handled in method throwException
Finally executed in throwException
Exception handled in main
Method doesNotThrowException
Finally executed in doesNotThrowException
End of method doesNotThrowException
```

Fig. 14.9 Demonstration of the **`try`**-**`catch`**-**`finally`** exception-handling mechanism (part 3 of 3).

The Java application in Fig. 14.10 demonstrates that when an exception thrown in a **`try`** block is *not* caught in a corresponding **`catch`** block, the exception will be detected in the next outer **`try`** block and handled by an appropriate **`catch`** block (if one is present) associated with that outer **`try`** block.

```
1  // Fig. 14.10: UsingExceptions.java
2  // Demonstration of stack unwinding.
3  public class UsingExceptions {
4
5     // execute application
6     public static void main( String args[] )
7     {
8        // call throwException to demonstrate stack unwinding
9        try {
10          throwException();
11       }
12
13       // catch exception thrown in throwException
14       catch ( Exception exception ) {
15          System.err.println( "Exception handled in main" );
16       }
17    }
18
19    // throwException throws an exception that is not caught in
20    // the body of this method
21    public static void throwException() throws Exception
22    {
23       // throw an exception and catch it in main
24       try {
25          System.out.println( "Method throwException" );
26          throw new Exception();       // generate exception
27       }
```

Fig. 14.10 Demonstration of stack unwinding (part 1 of 2).

```
28
29          // catch is incorrect type, so Exception not caught
30          catch( RuntimeException runtimeException ) {
31             System.err.println(
32                "Exception handled in method throwException" );
33          }
34
35          // finally block always executes
36          finally {
37             System.err.println( "Finally is always executed" );
38          }
39       }
40
41    }  // end class UsingExceptions
```

```
Method throwException
Finally is always executed
Exception handled in main
```

Fig. 14.10 Demonstration of stack unwinding (part 2 of 2).

When method **main** executes, line 10 in the **try** block calls **throwException** (lines 21–39). In the **try** block of method **throwException**, line 26 throws an **Exception**. This terminates the **try** block immediately and control proceeds to the **catch** handler at line 30. The type being caught (**RuntimeException**) is not an exact match with the thrown type (**Exception**) and is not a superclass of the thrown type, so the exception is not caught in method **throwException**. The exception must be handled before normal program execution can continue. Therefore, method **throwException** terminates (but not until its **finally** block executes) and returns control to the point from which it was called in the program (line 10). Line 10 is in the enclosing **try** block. If the exception has not yet been handled, the **try** block terminates and an attempt is made to catch the exception at line 14. The type being caught (**Exception**) matches the thrown type. Therefore, the **catch** handler processes the exception and the program terminates at the end of **main**.

As we have seen, a **finally** block executes for a variety of reasons, such as a **try** completing successfully, handling of an exception in a local **catch**, an exception being thrown for which no local **catch** is available or execution of a program control statement like a **return**, **break** or **continue**. Normally, the **finally** block executes, then behaves appropriately (we will call this **finally**'s "continuation action") depending on the reason program control entered the block. For example, if an exception is thrown in the **finally** block, the continuation action will be for *that* exception to be processed in the next enclosing **try** block. Unfortunately, if there was an exception that had not yet been caught, that exception is lost and the more recent exception is processed. This is dangerous.

Common Programming Error 14.13

If an exception is thrown for which no local **catch** *is available, when control enters the local* **finally** *block, the* **finally** *block could also* **throw** *an exception. If this happens, the first exception will be lost.*

Testing and Debugging Tip 14.11

Avoid placing code that can **`throw`** *an exception in a* **`finally`** *block. If such code is required, enclose the code in a* **`try/catch`** *within the* **`finally`** *block.*

Good Programming Practice 14.7

Java's exception-handling mechanism is intended to remove error-processing code from the main line of a program's code to improve program clarity. Do not place **`try/catch/finally`** *around every statement that may throw an exception. This makes programs difficult to read. Rather, place one* **`try`** *block around a significant portion of your code, follow that* **`try`** *block with* **`catch`** *blocks that handle each possible exception and follow the* **`catch`** *blocks with a single* **`finally`** *block (if one is required).*

Performance Tip 14.3

As a rule, resources should be released as soon as it is apparent that they are no longer needed. This makes these resources immediately available for reuse and can improve program performance.

Software Engineering Observation 14.15

If a **`try`** *block has a corresponding* **`finally`** *block, the* **`finally`** *block will execute even if the* **`try`** *block exits with* **`return`**, **`break`** *or* **`continue`**; *then the effect of the* **`return`**, **`break`** *or* **`continue`** *will occur.*

14.14 Using `printStackTrace` and `getMessage`

Exceptions derive from class **`Throwable`**. Class **`Throwable`** offers a **`printStackTrace`** method that prints the method call stack. By calling this method for a **`Throwable`** object that has been caught, a program can print the method call stack. Often, this is helpful in testing and debugging. Two other overloaded versions of **`printStackTrace`** enable the program to direct the stack trace to a **`PrintStream`** or **`PrintWriter`** stream. In this section, we consider an example that exercises the **`printStackTrace`** method and another useful method, **`getMessage`**.

Testing and Debugging Tip 14.12

All **`Throwable`** *objects contain a* **`printStackTrace`** *method that prints a stack trace for the object.*

Testing and Debugging Tip 14.13

An exception that is not caught eventually causes Java's default exception handler to run. This displays the name of the exception, the optional character string that was supplied when the exception was constructed and a complete execution stack trace. The stack trace shows the complete method call stack. This lets the programmer see the path of execution that led to the exception file-by-file (and thus class-by-class) and method-by-method. This information is helpful in debugging a program.

There are two constructors for class **`Throwable`**. The first constructor

```
public Throwable()
```

takes no arguments. The second constructor

```
public Throwable( String informationString )
```

takes the argument **informationString**, which is descriptive information about the **Throwable** object. The **informationString** stored in the **Throwable** object may be obtained with method **getMessage**.

Testing and Debugging Tip 14.14

Throwable *classes have a constructor that accepts a* ***String*** *argument. Using this form of the constructor is helpful in determining the source of the exception via method* ***getMessage****.*

Figure 14.11 demonstrates **getMessage** and **printStackTrace**. Method **getMessage** returns the descriptive **String** stored in an exception. Method **printStackTrace** outputs to the standard error stream (normally, the command line or console) an error message with the class name of the exception, the descriptive **String** stored in the exception and a list of the methods that had not completed execution when the exception was thrown (i.e., all methods currently residing on the method call stack).

In the program, **main** invokes **method1**, **method1** invokes **method2** and **method2** invokes **method3**. At this point, the method call stack for the program is

```
method3
method2
method1
main
```

with the last method called (**method3**) at the top and the first method called (**main**) at the bottom. When **method3** throws an **Exception** (line 36), a stack-trace message is generated and stored in the **Exception** object. The stack trace reflects the throw point in the code (i.e., line 36). Then, the stack unwinds to the first method in the method call stack in which the exception can be caught (i.e., **main** because it contains a **catch** handler for **Exception**). The **catch** handler then uses **getMessage** and **printStackTrace** on the **Exception** object **exception** to produce the output. Notice that the line numbers in the output window correspond to the line numbers in the program.

```
1  // Fig. 14.11: UsingExceptions.java
2  // Demonstrating the getMessage and printStackTrace
3  // methods inherited into all exception classes.
4  public class UsingExceptions {
5
6     // execute application
7     public static void main( String args[] )
8     {
9        // call method1
10       try {
11          method1();
12       }
13
14       // catch Exceptions thrown from method1
15       catch ( Exception exception ) {
16          System.err.println( exception.getMessage() + "\n" );
17          exception.printStackTrace();
18       }
19    }
```

Fig. 14.11 Using **getMessage** and **printStackTrace** (part 1 of 2).

```
20
21      // call method2; throw exceptions back to main
22      public static void method1() throws Exception
23      {
24         method2();
25      }
26
27      // call method3; throw exceptions back to method1
28      public static void method2() throws Exception
29      {
30         method3();
31      }
32
33      // throw Exception back to method2
34      public static void method3() throws Exception
35      {
36         throw new Exception( "Exception thrown in method3" );
37      }
38
39   }  // end class Using Exceptions
```

```
Exception thrown in method3

java.lang.Exception: Exception thrown in method3
        at UsingExceptions.method3(UsingExceptions.java:36)
        at UsingExceptions.method2(UsingExceptions.java:30)
        at UsingExceptions.method1(UsingExceptions.java:24)
        at UsingExceptions.main(UsingExceptions.java:11))
```

Fig. 14.11 Using **getMessage** and **printStackTrace** (part 2 of 2).

SUMMARY

- Some common examples of exceptions are memory exhaustion, an out-of-bounds array subscript, arithmetic overflow, division by zero and invalid method parameters.
- Exception handling is designed for dealing with synchronous malfunctions (i.e., those that occur as the result of a program's execution).
- Exception handling is used in situations in which a malfunction will be dealt with in a different scope from that which detected the malfunction.
- Exception handling should be used to process exceptions from software components such as methods, libraries and classes that are likely to be widely used and where it does not make sense for those components to handle their own exceptions.
- Exception handling should be used on large projects to handle error processing in a standardized manner for the entire project.
- Java exception handling is geared to situations in which the method that detects an error is unable to deal with it. Such a method will **throw** an exception. If the exception matches the type of the parameter in one of the **catch** blocks, the code for that **catch** block executes.
- The programmer encloses in a **try** block the code that may generate an exception. The **try** block is followed by one or more **catch** blocks. Each **catch** block specifies the type of exception it can catch and handle. Each **catch** block is an exception handler.

- If no exceptions are thrown in the **`try`** block, the exception handlers for that block are skipped. Then the program resumes execution after the last **`catch`** block, after executing a **`finally`** block if one is provided.
- Exceptions are thrown in a **`try`** block in a method or from a method called directly or indirectly from the **`try`** block.
- The operand of a **`throw`** can be of any class derived from **`Throwable`**. The immediate subclasses of **`Throwable`** are **`Error`** and **`Exception`**.
- **`RuntimeException`**s and **`Error`**s are said to be "unchecked." Non-**`RuntimeException`**s are said to be "checked." The checked exceptions thrown by a particular method must be specified in that method's **`throws`** clause.
- Exceptions are caught by the closest exception handler (for the **`try`** block from which the exception was thrown) specifying an appropriate type.
- An exception terminates the block in which the exception occurred.
- A handler may rethrow the object to an outer **`try`** block.
- **`catch( Exception exception )`** catches all **`Exception`**s.
- **`catch( Throwable throwable )`** catches all **`Exception`**s and **`Error`**s.
- If no handler matches a particular thrown object, the search for a match continues in an enclosing **`try`** block.
- Exception handlers are searched in order for an appropriate match based on type. The first handler that matches is executed. When that handler finishes executing, control resumes with the first statement after the last **`catch`** block.
- The order of the exception handlers affects how an exception is handled.
- A subclass object can be caught either by a handler specifying that subclass type or by handlers specifying the types of any direct or indirect superclasses of that subclass.
- If no handler is found for an exception, a non-GUI-based application terminates; an applet or a GUI-based application will return to its regular event handling.
- An exception handler cannot access variables in the scope of its **`try`** block because by the time the exception handler begins executing, the **`try`** block has expired. Information the handler needs is normally passed in the thrown object.
- Exception handlers can rethrow an exception. They can convert one type of exception into another by throwing a different exception. They can perform any necessary recovery and resume execution after the last exception handler. They can look at the situation causing the error, remove the cause of the error and retry by calling the original method that caused an exception. They can simply return some status value to their environment.
- A handler that catches a subclass object should be placed before a handler that catches a superclass object. If the superclass handler were first, it would catch superclass objects and the objects of subclasses of that superclass.
- When an exception is caught, it is possible that resources may have been allocated, but not yet released in the **`try`** block. A **`finally`** block should release these resources.
- It is possible that the handler that catches an exception may decide it cannot process the exception. In this case, the handler can simply rethrow the exception. A **`throw`** followed by the exception object name rethrows the exception.
- Even if a handler can process an exception, and regardless of whether it does any processing on that exception, the handler can rethrow the exception for further processing outside the handler. A rethrown exception is detected by the next enclosing **`try`** block (normally in a calling method) and is

handled by an appropriate exception handler (if there is one) listed after that enclosing **`try`** block.

- A **`throws`** clause lists the checked exceptions that may be thrown from a method. A method may **`throw`** the indicated exceptions, or it may **`throw`** subclass types. If a checked exception not listed in the **`throws`** clause is thrown, a syntax error occurs.
- A powerful reason for using inheritance with exceptions is to **`catch`** a variety of related errors easily with concise notation. One could certainly **`catch`** each type of subclass exception object individually, but it is more concise to simply **`catch`** the superclass exception object.

TERMINOLOGY

`ArithmeticException`
array exceptions
`ArrayIndexOutOfBoundsException`
business-critical computing
catch a group of exceptions
catch all exceptions
catch an exception
`catch` block
catch(Exception e)
`catch`-or-declare requirement
checked **`Exception`**s
`ClassCastException`
declare exceptions that can be thrown
default exception handler
`EmptyStackException`
`Error` class
`Error` class hierarchy
error handling
exception
`Exception` class
`Exception` class hierarchy
exception handler
exception handling
exception object
fault tolerance
`FileNotFoundException`
`finally` block
`getMessage` method of **`Throwable`** class
handle an exception
`IllegalAccessException`
`IncompatibleClassChangeException`
`instanceof` operator
`InstantiationException`
`InternalException`
`InterruptedException`
`IOException`
library exception classes
memory exhaustion
mission-critical computing
`NegativeArraySizeException`
`NoClassDefFoundException`
non-run-time exception
`null` reference
`NullPointerException`
`OutOfMemoryError`
`printStackTrace` method (**`Throwable`**)
resource leak
resumption model of exception handling
rethrow an exception
`RuntimeException`
stack unwinding
synchronous error
termination model of exception handling
throw an exception
throw point
`throw` statement
`Throwable` class
`throws` clause
`try` block
unchecked **`Exception`**s
`UnsatisfiedLinkException`

SELF-REVIEW EXERCISES

14.1 List five common examples of exceptions.

14.2 Why should exception-handling techniques not be used for conventional program control?

14.3 Why are exceptions particularly appropriate for dealing with errors produced by library classes and methods?

14.4 What is a “resource leak?”

14.5 If no exceptions are thrown in a **`try`** block, where does control proceed to when the **`try`** block completes execution?

14.6 What happens if an exception occurs and an appropriate exception handler cannot be found?

14.7 Give a key advantage of using **`catch(Exception e)`**.

14.8 Should a conventional applet or application catch **`Error`** objects?

14.9 What happens if several handlers match the type of the thrown object?

14.10 Why would a programmer specify a superclass type as the type of a **`catch`** handler, then throw objects of subclass types?

14.11 How might a **`catch`** handler be written to process related types of errors without using inheritance among exception classes?

14.12 What is the key reason for using **`finally`** blocks?

14.13 Does throwing an **`Exception`** have to cause program termination?

14.14 What happens when a **`catch`** handler throws an **`Exception`**?

14.15 What happens to a local reference in a **`try`** block when that block throws an **`Exception`**?

ANSWERS TO SELF-REVIEW EXERCISES

14.1 Memory exhaustion, array subscript out of bounds, arithmetic overflow, division by zero, invalid method parameters.

14.2 (a) **`Exception`** handling is designed to handle infrequently occurring situations that often result in program termination, so compiler writers are not required to implement exception handling to perform optimally. (b) Flow of control with conventional control structures is generally clearer and more efficient than with exceptions. (c) Problems can occur because the stack is unwound when an exception occurs and resources allocated prior to the exception may not be freed. (d) The "additional" exceptions can get in the way of genuine error-type exceptions. It becomes more difficult for the programmer to keep track of the larger number of exception cases.

14.3 It is unlikely that library classes and methods could perform error processing that would meet the unique needs of all users.

14.4 A resource leak occurs when an executing program does not properly release a resource when the resource is no longer needed. If the program attempts to use the resource again in the future, the program may not be able to access the resource.

14.5 The exception handlers (in the **`catch`** blocks) for that **`try`** block are skipped, and the program resumes execution after the last **`catch`** block. If there is a **`finally`** block, it is executed and the program resumes execution after the **`finally`** block.

14.6 A non-GUI-based application terminates; an applet or a GUI-based application resumes regular event processing.

14.7 The form **`catch(Exception e)`** catches any type of exception thrown in a **`try`** block. An advantage is that no thrown **`Exception`** can slip by.

14.8 **`Error`**s are usually serious problems with the underlying Java system; most programs will not want to catch **`Error`**s.

14.9 The first matching **`Exception`** handler after the **`try`** block is executed.

14.10 This is a nice way to catch related types of exceptions, but it should be used carefully.

14.11 Provide a single **`Exception`** subclass and **`catch`** handler for a group of exceptions. As each exception occurs, the exception object can be created with different instance data. The **`catch`** handler can examine this data to distinguish the type of the **`Exception`**.

14.12 The **`finally`** block is the preferred means for preventing resource leaks.

14.13 No, but it does terminate the block in which the **`Exception`** is thrown.

14.14 The exception will be processed by a **`catch`** handler (if one exists) associated with the **`try`** block (if one exists) enclosing the **`catch`** handler that caused the exception.

14.15 The reference is removed from memory, and the reference count for the referenced object is decremented. If the reference count is zero, the object is marked for garbage collection.

EXERCISES

14.16 Under what circumstances would you use the following **`catch`** handler?

```
catch ( Exception exception ) {
   throw exception;
}
```

14.17 List the benefits of exception handling over conventional means of error processing.

14.18 Describe an object-oriented technique for handling related exceptions.

14.19 Until this chapter, we have found that dealing with errors detected by constructors is a bit awkward. Explain why exception handling is an effective means for dealing with constructor failure.

14.20 Suppose a program throws an exception and the appropriate exception handler begins executing. Now suppose that the exception handler itself throws the same exception. Does this create an infinite recursion? Explain your answer.

14.21 Use inheritance to create an exception superclass and various exception subclasses. Write a program to demonstrate that the **`catch`** specifying the superclass catches subclass exceptions.

14.22 Write a Java program that shows that not all finalizers for objects constructed in a block are necessarily called after an exception is thrown from that block.

14.23 Write a Java program that demonstrates how various exceptions are caught with

```
catch ( Exception exception )
```

14.24 Write a Java program that shows that the order of exception handlers is important. If you try to catch a superclass exception type before a subclass type, the compiler should generate errors. Explain why these errors occur.

14.25 Write a Java program that shows a constructor passing information about constructor failure to an exception handler after a **`try`** block.

14.26 Write a Java program that illustrates rethrowing an exception.

14.27 Write a Java program that shows that a method with its own **`try`** block does not have to catch every possible error generated within the **`try`**. Some exceptions can slip through to, and be handled in, other scopes.

15

Multithreading

Objectives

- To understand the notion of multithreading.
- To appreciate how multithreading can improve performance.
- To understand how to create, manage and destroy threads.
- To understand the life cycle of a thread.
- To study several examples of thread synchronization.
- To understand thread priorities and scheduling.
- To understand daemon threads and thread groups.

The spider's touch, how exquisitely fine!
Feels at each thread, and lives along the line.
Alexander Pope

A person with one watch knows what time it is; a person with two watches is never sure.
Proverb

Conversation is but carving!
Give no more to every guest,
Than he's able to digest.
Jonathan Swift

Learn to labor and to wait.
Henry Wadsworth Longfellow

The most general definition of beauty…Multeity in Unity.
Samuel Taylor Coleridge

Outline

15.1 Introduction
15.2 Class `Thread`: An Overview of the `Thread` Methods
15.3 Thread States: Life Cycle of a Thread
15.4 Thread Priorities and Thread Scheduling
15.5 Thread Synchronization
15.6 Producer/Consumer Relationship without Thread Synchronization
15.7 Producer/Consumer Relationship with Thread Synchronization
15.8 Producer/Consumer Relationship: The Circular Buffer
15.9 Daemon Threads
15.10 `Runnable` Interface
15.11 Thread Groups
15.12 (Optional Case Study) Thinking About Objects: Multithreading
15.13 (Optional) Discovering Design Patterns: Concurrent Design Patterns

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

15.1 Introduction

It would be nice if we could "do one thing at a time" and "do it well," but that is simply not how the world works. The human body performs a great variety of operations *in parallel,* or as we will say throughout this chapter, *concurrently.* Respiration, blood circulation and digestion, for example, can occur concurrently. All of the senses—seeing, touching, smelling, tasting and hearing—can all occur concurrently. An automobile can be accelerating, turning, air conditioning and playing music concurrently. Computers, too, perform operations concurrently. It is common today for desktop personal computers to be compiling a program, printing a file and receiving e-mail messages over a network concurrently.

Concurrency is important in our lives. Ironically, though, most programming languages do not enable programmers to specify concurrent activities. Rather, programming languages generally provide only a simple set of control structures that enable programmers to perform one action at a time then proceed to the next action after the previous one is finished. The kind of concurrency that computers perform today normally is implemented as operating systems "primitives" available only to highly experienced "systems programmers."

The Ada programming language developed by the United States Department of Defense made concurrency primitives widely available to defense contractors building command and control systems. But Ada has not been widely used in universities and commercial industry.

Java is unique among popular general-purpose programming languages in that it makes concurrency primitives available to the applications programmer. The programmer specifies that applications contain threads of execution, each thread designating a portion of a program that may execute concurrently with other threads. This capability, called *multithreading,* gives the Java programmer powerful capabilities not available in C and C++, the languages on which Java is based. C and C++ are called single-threaded languages.

[*Note*: On many computer platforms, C and C++ programs can perform multithreading by using system specific code libraries.]

Software Engineering Observation 15.1

Unlike many languages that do not have built-in multithreading (such as C and C++) and must therefore make calls to operating system multithreading primitives, Java includes multithreading primitives as part of the language itself (actually in classes **`Thread`**, **`ThreadGroup`**, **`ThreadLocal`** *and* **`ThreadDeath`** *of the* **`java.lang`** *package). This encourages the use of multithreading among a larger part of the applications-programming community.*

We will discuss many applications of concurrent programming. When programs download large files such as audio clips or video clips from the World Wide Web, we do not want to wait until an entire clip is downloaded before starting the playback. So we can put multiple threads to work: One that downloads a clip and another that plays the clip so that these activities, or tasks, may proceed concurrently. To avoid choppy playback, we will coordinate the threads so that the player thread does not begin until there is a sufficient amount of the clip in memory to keep the player thread busy.

Another example of multithreading is Java's automatic garbage collection. In C and C++, the programmer is responsible for reclaiming dynamically allocated memory. Java provides a garbage collector thread that reclaims dynamically allocated memory that the program no longer needs.

Testing and Debugging Tip 15.1

In C and C++, programmers must provide explicit statements that reclaim dynamically allocated memory. When memory is not reclaimed (because a programmer forgets to do so, because of a logic error or because an exception diverts program control), this results in an all-too-common error called a memory leak that can eventually exhaust the supply of free memory and may cause premature program termination. Java's automatic garbage collection eliminates the vast majority of memory leaks, that is, those that are due to orphaned (unreferenced) objects.

Java's garbage collector runs as a low-priority thread. When Java determines that there are no longer any references to an object, it marks the object for eventual garbage collection. The garbage-collector thread runs when processor time is available and when there are no higher priority runnable threads. However, the garbage collector will run immediately when the system is out of memory.

Performance Tip 15.1

Setting an object reference to **`null`** *marks that object for eventual garbage collection (if there are no other references to the object). This can help conserve memory in a system in which a local variable that refers to an object does not go out of scope because the method in which it appears executes for a lengthy period.*

Writing multithreaded programs can be tricky. Although the human mind can perform many functions concurrently, humans find it difficult to jump between parallel "trains of thought." To see why multithreading can be difficult to program and understand, try the following experiment: open three books to page 1. Now try reading the books concurrently. Read a few words from the first book, then read a few words from the second book, then read a few words from the third book, then loop back and read the next few words from the first book, and so on. After a brief time, you will appreciate the challenges of multithreading: switching between books, reading briefly, remembering your place in each

book, moving the book you are reading closer so you can see it, pushing books you are not reading aside, and amidst all this chaos, trying to comprehend the content of the books!

Performance Tip 15.2

A problem with single-threaded applications is that lengthy activities must complete before other activities can begin. In a multithreaded application, threads can share a processor (or set of processors), so that multiple tasks are performed in parallel.

Although Java is perhaps the world's most portable programming language, certain portions of the language are nevertheless platform dependent. In particular, there are differences among the first three Java platforms implemented, namely the Solaris implementation and the Win32 implementations (i.e., Windows-based implementations for Windows 95 and Windows NT).

The Solaris Java platform runs a thread of a given priority to completion or until a higher priority thread becomes ready. At that point preemption occurs (i.e., the processor is given to the higher priority thread while the previously running thread must wait).

In the 32-bit Java implementations for Windows 95 and Windows NT, threads are timesliced. This means that each thread is given a limited amount of time (called a time *quantum*) to execute on a processor, and when that time expires the thread is made to wait while all other threads of equal priority get their chances to use their quantum in round-robin fashion. Then the original thread resumes execution. Thus, on Windows 95 and Windows NT, a running thread can be preempted by a thread of equal priority; whereas, on the Solaris implementation, a running Java thread can only be preempted by a higher priority thread. Future Solaris Java systems are expected to perform timeslicing as well.

Portability Tip 15.1

Java multithreading is platform dependent. Thus, a multithreaded application could behave differently on different Java implementations.

15.2 Class `Thread`: An Overview of the `Thread` Methods

In this section, we overview the various thread-related methods in the Java API. We use many of these methods in live-code examples throughout the chapter. The reader should refer to the Java API directly for more details on using each method, especially the exceptions thrown by each method.

Class **`Thread`** (package **`java.lang`**) has several constructors. The constructor

```
public Thread( String threadName )
```

constructs a **`Thread`** object whose name is **`threadName`**. The constructor

```
public Thread()
```

constructs a **`Thread`** whose name is **`"Thread-"`** concatenated with a number, like **`Thread-1`**, **`Thread-2`**, and so on.

The code that "does the real work" of a thread is placed in its ***`run`*** method. The **`run`** method can be overridden in a subclass of **`Thread`** or it may be implemented in a ***`Runnable`*** object; **`Runnable`** is an important Java interface that we study in Section 15.10.

A program launches a thread's execution by calling the thread's ***`start`*** method, which, in turn, calls method **`run`**. After **`start`** launches the thread, **`start`** returns to its

caller immediately. The caller then executes concurrently with the launched thread. The **start** method throws an ***IllegalThreadStateException*** if the thread it is trying to start has already been started.

The **static** method ***sleep*** is called with an argument specifying how long the currently executing thread should sleep (in milliseconds); while a thread sleeps, it does not contend for the processor, so other threads can execute. This can give lower priority threads a chance to run.

The ***interrupt*** method is called to interrupt a thread. The **static** method ***interrupted*** returns **true** if the current thread has been interrupted and **false** otherwise. A program can invoke a specific thread's ***isInterrupted*** method to determine whether that thread has been interrupted.

Method ***isAlive*** returns **true** if **start** has been called for a given thread and the thread is not dead (i.e., its controlling **run** method has not completed execution).

Method ***setName*** sets a **Thread**'s name. Method ***getName*** returns the name of the **Thread**. Method ***toString*** returns a **String** consisting of the name of the thread, the priority of the thread and the thread's ***ThreadGroup*** (discussed in Section 15.11).

The **static** method ***currentThread*** returns a reference to the currently executing **Thread**.

Method ***join*** waits for the **Thread** to which the message is sent to die before the calling **Thread** can proceed; no argument or an argument of 0 milliseconds to method **join** indicates that the current **Thread** will wait forever for the target **Thread** to die before the calling **Thread** proceeds. Such waiting can be dangerous; it can lead to two particularly serious problems called *deadlock* and *indefinite postponement*. We will discuss these momentarily.

Testing and Debugging Tip 15.2

*Method **dumpStack** is useful for debugging multithreaded applications. A program calls **static** method **dumpStack** to print a method-call stack trace for the current **Thread**.*

15.3 Thread States: Life Cycle of a Thread

At any time, a thread is said to be in one of several *thread states* (illustrated in Fig. 15.1). Let us say that a thread that was just created is in the *born* state. The thread remains in this state until the program calls the thread's **start** method, which causes the thread to enter the *ready* state (also known as the *runnable* state). The highest priority *ready* thread enters the *running state* (i.e., the thread begins executing), when the system assigns a processor to the thread. A thread enters the *dead* state when its **run** method completes or terminates for any reason—a *dead* thread eventually will be disposed of by the system.

One common way for a *running* thread to enter the blocked state is when the thread issues an input/output request. In this case, a blocked thread becomes ready when the I/O for which it is waiting completes. A blocked thread cannot use a processor even if one is available.

When the program calls method **sleep** in a running thread, that thread enters the sleeping state. A sleeping thread becomes ready after the designated sleep time expires. A sleeping thread cannot use a processor even if one is available. If the program calls method **interrupt** on a sleeping thread, that thread exits the sleeping state and becomes ready to execute.

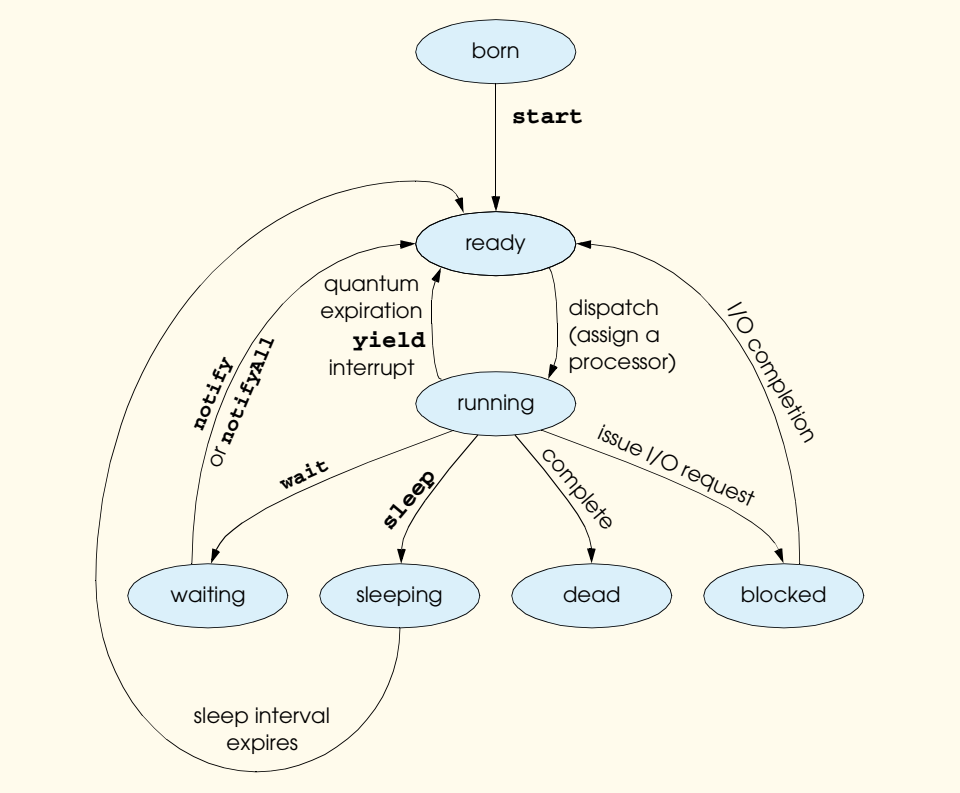


Fig. 15.1 State diagram showing the Life cycle of a thread.

When a running thread calls **`wait`**, the thread enters a waiting state for the particular object on which **`wait`** was called. One thread in the waiting state for a particular object becomes ready on a call to **`notify`** issued by another thread associated with that object. Every thread in the waiting state for a given object becomes ready on a call to **`notifyAll`** by another thread associated with that object. The **`wait`**, **`notify`** and **`notifyAll`** methods will be discussed in more depth shortly, when we consider monitors.

A thread enters the *dead state* when its **`run`** method either completes or throws an uncaught exception.

15.4 Thread Priorities and Thread Scheduling

Every Java applet or application is multithreaded. Every Java thread has a priority in the range **`Thread.MIN_PRIORITY`** (a constant of 1) and **`Thread.MAX_PRIORITY`** (a constant of 10). By default, each thread is given priority **`Thread.NORM_PRIORITY`** (a constant of 5). Each new thread inherits the priority of the thread that creates it.

Some Java platforms support a concept called *timeslicing* and some do not. Without timeslicing, each thread in a set of equal-priority threads runs to completion (unless the thread leaves the running state and enters the waiting, sleeping or blocked state, or the

thread gets interrupted by a higher priority thread) before that thread's peers get a chance to execute. With timeslicing, each thread receives a brief burst of processor time called a *quantum* during which that thread can execute. At the completion of the quantum, even if that thread has not finished executing, the operating system takes the processor away from that thread and gives it to the next thread of equal priority (if one is available).

The job of the Java scheduler is to keep the highest priority thread running at all times, and if timeslicing is available, to ensure that several equally high-priority threads each execute for a quantum in round-robin fashion (i.e., these threads can be timesliced). Figure 15.2 illustrates Java's multilevel priority queue for threads. In the figure, threads A and B each execute for a quantum in round-robin fashion until both threads complete execution. Next, thread C runs to completion. Then, threads D, E and F each execute for a quantum in round-robin fashion until they all complete execution. This process continues until all threads run to completion. Note that new higher-priority threads could postpone—possibly indefinitely—the execution of lower priority threads. Such *indefinite postponement* often is referred to more colorfully as *starvation*.

A thread's priority can be adjusted with method **`setPriority`**, which takes an **`int`** argument. If the argument is not in the range 1 through 10, **`setPriority`** throws an **`IllegalArgumentException`**. Method **`getPriority`** returns the thread's priority.

A thread can call the **`yield`** method to give other threads a chance to execute. Actually, whenever a higher priority thread becomes ready, the operating system preempts the current thread. So, a thread cannot **`yield`** to a higher priority thread, because the first thread would have been preempted when the higher priority thread became ready. Similarly, **`yield`** always allows the highest priority-*ready* thread to run, so if only lower priority threads are ready at the time of a **`yield`** call, the current thread will be the highest priority thread and will continue executing. Therefore, a thread **`yield`**s to give threads of an equal priority a chance to run. On a timesliced system this is unnecessary, because threads of equal priority will each execute for their quantum (or until they lose the processor for some other reason), and other threads of equal priority will execute in round-robin fashion. Thus **`yield`** is appropriate for nontimesliced systems in which a thread would ordinarily run to completion before another thread of equal priority would have an opportunity to run.

Performance Tip 15.3

On nontimesliced systems, cooperating threads of equal priority should periodically call **`yield`** *to enable their peers to proceed smoothly.*

Portability Tip 15.2

Java applets and applications should be programmed to work on all Java platforms to realize Java's goal of true portability. When designing applets and applications that use threads, you must consider the threading capabilities of all the platforms on which the applets and applications will execute.

A thread executes unless it dies, it becomes blocked by the operating system for input/output (or some other reason), it calls **`sleep`**, it calls **`wait`**, it calls **`yield`**, it is preempted by a thread of higher priority or its quantum expires. A thread with a higher priority than the running thread can become ready (and hence preempt the running thread) if a sleeping thread finishes sleeping, if I/O completes for a thread waiting for that I/O or if either **`notify`** or **`notifyAll`** is called on a thread that has called **`wait`**.

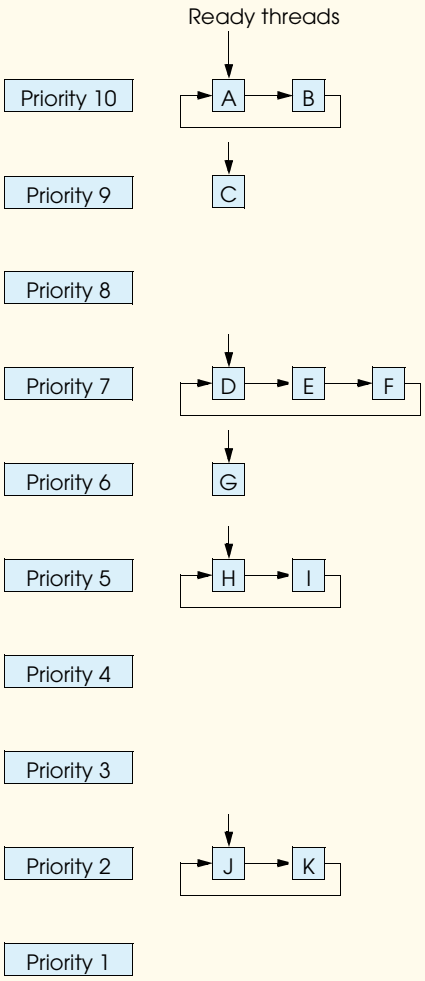


Fig. 15.2 Java thread priority scheduling.

The application of Fig. 15.3 demonstrates basic threading techniques, including creation of a class derived from **`Thread`**, construction of a **`Thread`** and using the **`Thread`** class **`sleep`** method. Each thread of execution we create in the program displays its name after sleeping for a random amount of time between 0 and 5 seconds. You will see that the **`main`** method (i.e., the ***`main`*** *thread of execution*) terminates before the application terminates. The program consists of two classes—**`ThreadTester`** (lines 4–28) and **`PrintThread`** (lines 33–71).

Class **`PrintThread`** inherits from **`Thread`**, so that each object of the class can execute in parallel. The class consists of instance variable **`sleepTime`**, a constructor and a

run method. Variable **sleepTime** stores a random integer value chosen when the program creates a **PrintThread** object. Each **PrintThread** object sleeps for the amount of time specified by its **sleepTime**, then outputs its name.

The **PrintThread** constructor (lines 38–48) initializes **sleepTime** to a random integer between 0 and 4999 (0 to 4.999 seconds). Then, the constructor outputs the name of the thread and the value of **sleepTime** to show the values for the particular **PrintThread** being constructed. The name of each thread is specified as a **String** argument to the **PrintThread** constructor and is passed to the superclass constructor at line 40. [*Note*: It is possible to allow class **Thread** to choose a name for your thread by using the **Thread** class's default constructor.

```
1  // Fig. 15.3: ThreadTester.java
2  // Show multiple threads printing at different intervals.
3
4  public class ThreadTester {
5
6     // create and start threads
7     public static void main( String args[] )
8     {
9        PrintThread thread1, thread2, thread3, thread4;
10
11       // create four PrintThread objects
12       thread1 = new PrintThread( "thread1" );
13       thread2 = new PrintThread( "thread2" );
14       thread3 = new PrintThread( "thread3" );
15       thread4 = new PrintThread( "thread4" );
16
17       System.err.println( "\nStarting threads" );
18
19       // start executing PrintThreads
20       thread1.start();
21       thread2.start();
22       thread3.start();
23       thread4.start();
24
25       System.err.println( "Threads started\n" );
26    }
27
28 }  // end class ThreadTester
29
30 // Each object of this class picks a random sleep interval.
31 // When a PrintThread executes, it prints its name, sleeps,
32 // prints its name again and terminates.
33 class PrintThread extends Thread {
34    private int sleepTime;
35
36    // PrintThread constructor assigns name to thread
37    // by calling superclass Thread constructor
```

Fig. 15.3 Multiple threads printing at random intervals (part 1 of 3).

```
38      public PrintThread( String name )
39      {
40         super( name );
41
42         // sleep between 0 and 5 seconds
43         sleepTime = (int) ( Math.random() * 5000 );
44
45         // display name and sleepTime
46         System.err.println(
47            "Name: " + getName() + ";  sleep: " + sleepTime );
48      }
49
50      // control thread's execution
51      public void run()
52      {
53         // put thread to sleep for a random interval
54         try {
55            System.err.println( getName() + " going to sleep" );
56
57            // put thread to sleep
58            Thread.sleep( sleepTime );
59         }
60
61         // if thread interrupted during sleep, catch exception
62         // and display error message
63         catch ( InterruptedException interruptedException ) {
64            System.err.println( interruptedException.toString() );
65         }
66
67         // print thread name
68         System.err.println( getName() + " done sleeping" );
69      }
70
71   }  // end class PrintThread
```

```
Name: thread1;  sleep: 3593
Name: thread2;  sleep: 2653
Name: thread3;  sleep: 4465
Name: thread4;  sleep: 1318

Starting threads
Threads started

thread1 going to sleep
thread2 going to sleep
thread3 going to sleep
thread4 going to sleep
thread4 done sleeping
thread2 done sleeping
thread1 done sleeping
thread3 done sleeping
```

Fig. 15.3 Multiple threads printing at random intervals (part 2 of 3).

```
Name: thread1;  sleep: 2753
Name: thread2;  sleep: 3199
Name: thread3;  sleep: 2797
Name: thread4;  sleep: 4639

Starting threads
Threads started

thread1 going to sleep
thread2 going to sleep
thread3 going to sleep
thread4 going to sleep
thread1 done sleeping
thread3 done sleeping
thread2 done sleeping
thread4 done sleeping
```

Fig. 15.3 Multiple threads printing at random intervals (part 3 of 3).

When the program invokes a **PrintThread**'s **start** method (inherited from **Thread**), the **PrintThread** object enters the *ready* state. When the system assigns a processor to the **PrintThread** object, it enters the *running* state and its **run** method begins execution. Method **run** (lines 51–69) prints a **String** in the command window indicating that the thread is going to sleep (line 55), then invokes the **sleep** method (line 58) to place the thread into a *sleeping* state. At this point, the thread loses the processor, and the system allows another thread to execute. When the thread awakens, it is placed in a *ready* state again until the system assigns to the thread. When the **PrintThread** object enters the *running* state again, line 68 outputs the thread's name (indicating that the thread is done sleeping), the **run** method terminates and the thread object enters the *dead* state. Note that method **sleep** can throw a checked **InterruptedException** (if another thread invokes the sleeping thread's **interrupt** method); therefore, **sleep** must be called in a **try** block (in this example, we simply output the **String** representation of the exception if one occurs). Note that this example uses **System.err** rather than **System.out** to output lines of text. **System.err** represents the standard error object, which outputs error messages (normally to the command window). **System.out** performs buffered output—it is possible that a message output with **System.out** will not be output immediately. On the other hand, **System.err** uses unbuffered output—messages appear immediately when they are output. Using **System.err** in a multithreaded program helps ensure that the messages from our program are output in the correct order.

Class **ThreadTester**'s **main** method (lines 7–26) creates four objects of class **PrintThread** (lines 12–15) and invokes the **Thread** class **start** method on each one (lines 20–23) to place all four **PrintThread** objects in a *ready* state. Note that the program terminates execution when the last **PrintThread** awakens and prints its name. Also, note that the **main** method (i.e., the **main** thread of execution) terminates after starting the four **PrintThread**s, but the application does not terminate until the last thread dies.

15.5 Thread Synchronization

Java uses *monitors* (as discussed by C.A.R. Hoare in his 1974 paper cited in Exercise 15.24) to perform synchronization. Every object with **`synchronized`** methods has a monitor. The monitor allows one thread at a time to execute a **`synchronized`** method on the object. This is accomplished by *locking* the object when the program invokes the **`synchronized`** method—also known as *obtaining the lock*. If there are several **`synchronized`** methods, only one **`synchronized`** method may be active on an object at once; all other threads attempting to invoke **`synchronized`** methods must wait. When a **`synchronized`** method finishes executing, the lock on the object is released and the monitor lets the highest priority-*ready* thread attempting to invoke a **`synchronized`** method proceed. [*Note*: Java also has ***`synchronized`*** *blocks* of code, which are discussed in the example of Section 15.10].

A thread executing in a **`synchronized`** method may determine that it cannot proceed, so the thread voluntarily calls **`wait`**. This removes the thread from contention for the processor and from contention for the monitor object. The thread now waits in the *waiting* state while other threads try to enter the monitor object. When a thread executing a **`synchronized`** method completes or satisfies the condition on which another thread may be waiting, the thread can **`notify`** a waiting thread to become *ready* again. At this point, the original thread can attempt to reacquire the lock on the monitor object and execute. The **`notify`** acts as a signal to the waiting thread that the condition for which the waiting thread has been waiting is now satisfied, so the waiting thread can reenter the monitor. If a thread calls **`notifyAll`**, then all threads waiting for the monitor become eligible to reenter the monitor (that is, they are all placed in a *ready* state). Remember that only one of those threads can obtain the lock on the object at a time—other threads that attempt to acquire the same lock will be *blocked* by the operating system until the lock becomes available again. Methods **`wait`**, **`notify`** and **`notifyAll`** are inherited by all classes from class **`Object`**. So any object may have a monitor.

Common Programming Error 15.1

Threads in the waiting state for a monitor object must be awakened explicitly with a ***`notify`*** *(or* ***`interrupt`****) or the thread will wait forever. This may cause deadlock. [Note: There are versions of method* ***`wait`*** *that receive arguments indicating the maximum wait time. If the thread is not notified in the specified amount of time, the thread becomes ready to execute.]*

Testing and Debugging Tip 15.3

Be sure that every call to ***`wait`*** *has a corresponding call to* ***`notify`*** *that eventually will end the waiting or call* ***`notifyAll`*** *as a safeguard.*

Performance Tip 15.4

Synchronization to achieve correct multithreaded behavior can make programs run more slowly due to the monitor overhead and frequently moving threads between the running, waiting and ready states. However, there is not much to say for highly efficient, incorrect multithreaded programs!

Testing and Debugging Tip 15.4

The locking that occurs with the execution of ***`synchronized`*** *methods could lead to deadlock if the locks are never released. When exceptions occur, Java's exception mechanism coordinates with Java's synchronization mechanism to release appropriate synchronization locks to avoid these kinds of deadlocks.*

Monitor objects maintain a list of all threads waiting to enter the monitor object to execute **synchronized** methods. A thread is inserted in the list and waits for the object if that thread calls a **synchronized** method of the object while another thread is already executing in a **synchronized** method of that object. A thread also is inserted in the list if the thread calls **wait** while operating inside the object. However, it is important to distinguish between waiting threads that blocked because the monitor was busy and threads that explicitly called **wait** inside the monitor. Upon completion of a **synchronized** method, outside threads that blocked because the monitor was busy can proceed to enter the object. Threads that explicitly invoked **wait** can proceed only when notified via a call by another thread to **notify** or **notifyAll**. When it is acceptable for a waiting thread to proceed, the scheduler selects the thread with the highest priority.

Common Programming Error 15.2

It is an error if a thread issues a **wait**, *a* **notify** *or a* **notifyAll** *on an object without having acquired a lock for the object. This causes an* **IllegalMonitorStateException**.

15.6 Producer/Consumer Relationship without Thread Synchronization

In a producer/consumer relationship, a *producer thread* calling a *produce* method may see that the consumer thread has not read the last message from a shared region of memory called a *buffer*, so the producer thread will call **wait**. When a *consumer thread* reads the message, it will call **notify** to allow a waiting producer to proceed. When a consumer thread enters the monitor and finds the buffer empty, it calls **wait**. A producer finding the buffer empty writes to the buffer, then calls **notify** so a waiting consumer can proceed.

Shared data can get corrupted if we do not synchronize access among multiple threads. Consider a producer/consumer relationship in which a producer thread deposits a sequence of numbers (we use 1, 2, 3, …) into a slot of shared memory. The consumer thread reads this data from the shared memory and prints it. We print what the producer produces as it produces it and what the consumer consumes as it consumes it. The program of Fig. 15.4–Fig. 15.7 demonstrates a producer and a consumer accessing a single shared cell of memory (**int** variable **sharedInt** in Fig. 15.6) without any synchronization. The threads are not synchronized, so data can be lost if the producer places new data into the slot before the consumer consumes the previous data. Also, data can be "doubled" if the consumer consumes data again before the producer produces the next item. To show these possibilities, the consumer thread in this example keeps a total of all the values it reads. The producer thread produces values from 1 to 10. If the consumer reads each value produced only once, the total would be 55. However, if you execute this program several times, you will see that the total is rarely, if ever, 55.

The program consists of four classes—**ProduceInteger** (Fig. 15.4), **ConsumeInteger** (Fig. 15.5), **HoldIntegerUnsynchronized** (Fig. 15.6) and **SharedCell** (Fig. 15.7).

Class **ProduceInteger** (Fig. 15.4)—a subclass of **Thread**—consists of instance variable **sharedObject** (line 4), a constructor (lines 7–11) and a **run** method (lines 15–37). The constructor initializes instance variable **sharedObject** (line 10) to refer to the

HoldIntegerUnsynchronized object **shared**, which was passed as an argument. Class **ProduceInteger**'s **run** method (lines 15–37) consists of a **for** structure that loops 10 times. Each iteration of the loop first invokes method **sleep** to put the **ProduceInteger** object into the sleeping state for a random time interval between 0 and 3 seconds. When the thread awakens, line 31 calls class **HoldIntegerUnsynchronized**'s **setSharedInt** method and passes the value of control variable **count** to set the shared object's instance variable **sharedInt**. When the loop completes, lines 34–36 display a line of text in the command window indicating that the thread finished producing data and that the thread is terminating, then the thread terminates (i.e., the thread dies).

```
1  // Fig. 15.4: ProduceInteger.java
2  // Definition of threaded class ProduceInteger
3  public class ProduceInteger extends Thread {
4     private HoldIntegerUnsynchronized sharedObject;
5
6     // initialize ProduceInteger thread object
7     public ProduceInteger( HoldIntegerUnsynchronized shared )
8     {
9        super( "ProduceInteger" );
10       sharedObject = shared;
11    }
12
13    // ProduceInteger thread loops 10 times and calls
14    // sharedObject's setSharedInt method each time
15    public void run()
16    {
17       for ( int count = 1; count <= 10; count++ ) {
18
19          // sleep for a random interval
20          try {
21             Thread.sleep( ( int ) ( Math.random() * 3000 ) );
22          }
23
24          // process InterruptedException during sleep
25          catch( InterruptedException exception ) {
26             System.err.println( exception.toString() );
27          }
28
29          // call sharedObject method from this
30          // thread of execution
31          sharedObject.setSharedInt( count );
32       }
33
34       System.err.println(
35          getName() + " finished producing values" +
36          "\nTerminating " + getName() );
37    }
38
39 }  // end class ProduceInteger
```

Fig. 15.4 Class **ProduceInteger** represents the producer in a producer/consumer relationship.

Class **ConsumeInteger** (Fig. 15.5)—a subclass of **Thread**—consists of instance variable **sharedObject** (line 4), a constructor (lines 7–11) and a **run** method (lines 15–39). The constructor initializes instance variable **sharedObject** (line 10) to refer to the **HoldIntegerUnsynchronized** object **shared** that was passed as an argument. Class **ConsumeInteger**'s **run** method (lines 15–39) consists of a **do/while** structure that loops until the value 10 is read from the **HoldIntegerUnsynchronized** object to which **sharedObject** refers. Each iteration of the loop invokes method **sleep** to put the **ConsumeInteger** object into the sleeping state for a random time interval between 0 and 3 seconds. Next, line 31 invokes class **HoldIntegerUnsynchronized**'s **getSharedInt** method to get the value of the shared object's instance variable **sharedInt**. Then, line 32 adds the value returned by **getSharedInt** to the variable **sum**. When the loop completes, the **ConsumeInteger** thread displays a line in the command window indicating that it has finished consuming data and terminates (i.e., the thread dies).

```
1  // Fig. 15.5: ConsumeInteger.java
2  // Definition of threaded class ConsumeInteger
3  public class ConsumeInteger extends Thread {
4     private HoldIntegerUnsynchronized sharedObject;
5
6     // initialize ConsumerInteger thread object
7     public ConsumeInteger( HoldIntegerUnsynchronized shared )
8     {
9        super( "ConsumeInteger" );
10       sharedObject = shared;
11    }
12
13    // ConsumeInteger thread loops until it receives 10
14    // from sharedObject's getSharedInt method
15    public void run()
16    {
17       int value, sum = 0;
18
19       do {
20
21          // sleep for a random interval
22          try {
23             Thread.sleep( (int) ( Math.random() * 3000 ) );
24          }
25
26          // process InterruptedException during sleep
27          catch( InterruptedException exception ) {
28             System.err.println( exception.toString() );
29          }
30
31          value = sharedObject.getSharedInt();
32          sum += value;
33
34       } while ( value != 10 );
35
```

Fig. 15.5 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 1 of 2).

```
36          System.err.println(
37             getName() + " retrieved values totaling: " + sum +
38             "\nTerminating " + getName() );
39       }
40
41    }  // end class ConsumeInteger
```

Fig. 15.5 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 2 of 2).

Class **HoldIntegerUnsynchronized** consists of instance variable **sharedInt** (line 4), method **setSharedInt** (lines 7–13) and method **getSharedInt** (lines 16–22). Methods **setSharedInt** and **getSharedInt** do not synchronize access to instance variable **sharedInt**. Note that each method uses **static Thread** method **currentThread** to obtain a reference to the currently executing thread, then use **Thread** method **getName** to obtain the thread's name.

Class **SharedCell**'s **main** method (lines 6–20) instantiates the shared **HoldIntegerUnsynchronized** object **sharedObject** and uses it as the argument to the constructors for the **ProduceInteger** object **producer** and the **ConsumeInteger** object **consumer**. The **sharedObject** contains the data that will be shared between the two threads. Next, method **main** invokes the **Thread** class **start** method on the **producer** and **consumer** threads to place them in the *ready* state. This launches these threads.

```
1  // Fig. 15.6: HoldIntegerUnsynchronized.java
2  // Definition of class HoldIntegerUnsynchronized.
3  public class HoldIntegerUnsynchronized {
4     private int sharedInt = -1;
5
6     // unsynchronized method to place value in sharedInt
7     public void setSharedInt( int value )
8     {
9        System.err.println( Thread.currentThread().getName() +
10          " setting sharedInt to " + value );
11
12       sharedInt = value;
13    }
14
15    // unsynchronized method return sharedInt's value
16    public int getSharedInt()
17    {
18       System.err.println( Thread.currentThread().getName() +
19          " retrieving sharedInt value " + sharedInt );
20
21       return sharedInt;
22    }
23
24 }  // end class HoldIntegerUnsynchronized
```

Fig. 15.6 Class **HoldIntegerUnsynchronized** maintains the data shared between the producer and consumer threads.

```
1  // Fig. 15.7: SharedCell.java
2  // Show multiple threads modifying shared object.
3  public class SharedCell {
4
5     // execute application
6     public static void main( String args[] )
7     {
8        HoldIntegerUnsynchronized sharedObject =
9           new HoldIntegerUnsynchronized();
10
11       // create threads
12       ProduceInteger producer =
13          new ProduceInteger( sharedObject );
14       ConsumeInteger consumer =
15          new ConsumeInteger( sharedObject );
16
17       // start threads
18       producer.start();
19       consumer.start();
20    }
21
22 }  // end class SharedCell
```

```
ConsumeInteger retrieving sharedInt value -1
ConsumeInteger retrieving sharedInt value -1
ProduceInteger setting sharedInt to 1
ProduceInteger setting sharedInt to 2
ConsumeInteger retrieving sharedInt value 2
ProduceInteger setting sharedInt to 3
ProduceInteger setting sharedInt to 4
ProduceInteger setting sharedInt to 5
ConsumeInteger retrieving sharedInt value 5
ProduceInteger setting sharedInt to 6
ProduceInteger setting sharedInt to 7
ProduceInteger setting sharedInt to 8
ConsumeInteger retrieving sharedInt value 8
ConsumeInteger retrieving sharedInt value 8
ProduceInteger setting sharedInt to 9
ConsumeInteger retrieving sharedInt value 9
ConsumeInteger retrieving sharedInt value 9
ProduceInteger setting sharedInt to 10
ProduceInteger finished producing values
Terminating ProduceInteger
ConsumeInteger retrieving sharedInt value 10
ConsumeInteger retrieved values totaling: 49
Terminating ConsumeInteger
```

Fig. 15.7 Threads modifying a shared object without synchronization.

Ideally, we would like every value produced by the **ProduceInteger** object to be consumed exactly once by the **ConsumeInteger** object. However, when we study the output of Fig. 15.7, we see that the values 1, 3, 4, 6 and 7 are lost (i.e., never seen by the consumer) and that the values 8 and 9 are incorrectly retrieved more than once by the con-

sumer. Also, notice that the consumer twice retrieved value –1 (the default value of **sharedInt** set at line 5 of Fig. 15.6) before the producer ever assigned 1 to the **sharedInt** variable. This example clearly demonstrates that access to shared data by concurrent threads must be controlled carefully or a program may produce incorrect results.

To solve the problems of lost data and doubled data in the previous example, we will synchronize access of the concurrent producer and consumer threads to the shared data. Each method used by a producer or consumer to access the shared data is declared with the **synchronized** keyword. When a method declared **synchronized** is running in an object, the object is *locked* so no other **synchronized** method can run in that object at the same time.

15.7 Producer/Consumer Relationship with Thread Synchronization

The application in Fig. 15.8 demonstrates a producer and a consumer accessing a shared cell of memory with synchronization so that the consumer only consumes after the producer produces a value. Classes **ProduceInteger** (Fig. 15.8), **ConsumeInteger** (Fig. 15.9) and **SharedCell** (Fig. 15.11) are identical to Fig. 15.4, Fig. 15.5 and Fig. 15.7 except that they use the new class **HoldIntegerSynchronized** in this example.

Class **HoldIntegerSynchronized** (Fig. 15.10) contains two instance variables—**sharedInt** (line 6) and **writeable** (line 7). Also, method **setSharedInt** (lines 12–39) and method **getSharedInt** (lines 44–70) are now **synchronized** methods. Objects of class **HoldIntegerSynchronized** have monitors, because **HoldIntegerSynchronized** contains **synchronized** methods. Instance variable **writeable** is known as the monitor's *condition variable*—is a **boolean** used by methods **setSharedInt** and **getSharedInt** of class **HoldIntegerSynchronized**. If **writeable** is **true**, **setSharedInt** can place a value into variable **sharedInt**, because the variable currently does not contain information. However, this means **getSharedInt** currently cannot read the value of **sharedInt**. If **writeable** is **false**, **getSharedInt** can read a value from variable **sharedInt** because the variable currently does contain information. However, this means **setSharedInt** currently cannot place a value into **sharedInt**.

```
1  // Fig. 15.8: ProduceInteger.java
2  // Definition of threaded class ProduceInteger
3  public class ProduceInteger extends Thread {
4     private HoldIntegerSynchronized sharedObject;
5
6     // initialize ProduceInteger thread object
7     public ProduceInteger( HoldIntegerSynchronized shared )
8     {
9        super( "ProduceInteger" );
10       sharedObject = shared;
11    }
12
```

Fig. 15.8 Class **ProduceInteger** represents the producer in a producer/consumer relationship (part 1 of 2).

```
13     // ProduceInteger thread loops 10 times and calls
14     // sharedObject's setSharedInt method each time
15     public void run()
16     {
17        for ( int count = 1; count <= 10; count++ ) {
18
19           // sleep for a random interval
20           try {
21              Thread.sleep( ( int ) ( Math.random() * 3000 ) );
22           }
23
24           // process InterruptedException during sleep
25           catch( InterruptedException exception ) {
26              System.err.println( exception.toString() );
27           }
28
29           // call sharedObject method from this
30           // thread of execution
31           sharedObject.setSharedInt( count );
32        }
33
34        System.err.println(
35           getName() + " finished producing values" +
36           "\nTerminating " + getName() );
37     }
38
39  }  // end class ProduceInteger
```

Fig. 15.8 Class **ProduceInteger** represents the producer in a producer/consumer relationship (part 2 of 2).

```
1  // Fig. 15.9: ConsumeInteger.java
2  // Definition of threaded class ConsumeInteger
3  public class ConsumeInteger extends Thread {
4     private HoldIntegerSynchronized sharedObject;
5
6     // initialize ConsumerInteger thread object
7     public ConsumeInteger( HoldIntegerSynchronized shared )
8     {
9        super( "ConsumeInteger" );
10       sharedObject = shared;
11    }
12
13    // ConsumeInteger thread loops until it receives 10
14    // from sharedObject's getSharedInt method
15    public void run()
16    {
17       int value, sum = 0;
18
```

Fig. 15.9 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 1 of 2).

```
19          do {
20
21             // sleep for a random interval
22             try {
23                Thread.sleep( (int) ( Math.random() * 3000 ) );
24             }
25
26             // process InterruptedException during sleep
27             catch( InterruptedException exception ) {
28                System.err.println( exception.toString() );
29             }
30
31             value = sharedObject.getSharedInt();
32             sum += value;
33
34          } while ( value != 10 );
35
36          System.err.println(
37             getName() + " retrieved values totaling: " + sum +
38             "\nTerminating " + getName() );
39       }
40
41    }  // end class ConsumeInteger
```

Fig. 15.9 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 2 of 2).

When the **ProduceInteger** thread object invokes synchronized method **setSharedInt** (line 31 of Fig. 15.8), the thread acquires a lock on the **HoldIntegerSynchronized** monitor object. The **while** structure in **HoldIntegerSynchronized** at lines 14–25 tests the **writeable** variable with the condition **!writeable**. If this condition is **true**, the thread invokes method **wait**. This places the **ProduceInteger** thread object that called method **setSharedInt** into the waiting state for the **HoldIntegerSynchronized** object and *releases the lock* on it. Now another thread can invoke a **synchronized** method on the **HoldIntegerSynchronized** object.

The **ProduceInteger** object remains in the waiting state until it is *notified* that it may proceed—at which point it enters the *ready* state and waits for the system to assign a processor to it. When the **ProduceInteger** object reenters the *running* state, it reacquires the lock on the **HoldIntegerSynchronized** object implicitly and the **setSharedInt** method continues executing in the **while** structure with the next statement after **wait**. There are no more statements, so the program reevaluates the **while** condition. If the condition is **false**, the program outputs a line to the command window indicating that the producer is setting **sharedInt** to a new value, assigns **value** to **sharedInt**, sets **writeable** to **false** to indicate that the shared memory is now full (i.e., a consumer can read the value and a producer cannot put another value there yet) and invokes method **notify**. If there are any waiting threads, one of those waiting threads enters the *ready* state, indicating that the thread can now attempt its task again (as soon as it is assigned a processor). The **notify** method returns immediately and method **setSharedInt** returns to its caller.

```
1  // Fig. 15.10: HoldIntegerSynchronized.java
2  // Definition of class HoldIntegerSynchronized that
3  // uses thread synchronization to ensure that both
4  // threads access sharedInt at the proper times.
5  public class HoldIntegerSynchronized {
6     private int sharedInt = -1;
7     private boolean writeable = true;  // condition variable
8
9     // synchronized method allows only one thread at a time to
10    // invoke this method to set the value for a particular
11    // HoldIntegerSynchronized object
12    public synchronized void setSharedInt( int value )
13    {
14       while ( !writeable ) {  // not the producer's turn
15
16          // thread that called this method must wait
17          try {
18             wait();
19          }
20
21          // process Interrupted exception while thread waiting
22          catch ( InterruptedException exception ) {
23             exception.printStackTrace();
24          }
25       }
26
27       System.err.println( Thread.currentThread().getName() +
28          " setting sharedInt to " + value );
29
30       // set new sharedInt value
31       sharedInt = value;
32
33       // indicate that producer cannot store another value until
34       // a consumer retrieve current sharedInt value
35       writeable = false;
36
37       // tell a waiting thread to become ready
38       notify();
39    }
40
41    // synchronized method allows only one thread at a time to
42    // invoke this method to get the value for a particular
43    // HoldIntegerSynchronized object
44    public synchronized int getSharedInt()
45    {
46       while ( writeable ) {   // not the consumer's turn
47
48          // thread that called this method must wait
49          try {
50             wait();
51          }
52
```

Fig. 15.10 Class **HoldIntegerSynchronized** monitors access to a shared integer (part 1 of 2).

```
53            // process Interrupted exception while thread waiting
54            catch ( InterruptedException exception ) {
55               exception.printStackTrace();
56            }
57         }
58
59         // indicate that producer cant store another value
60         // because a consumer just retrieved sharedInt value
61         writeable = true;
62
63         // tell a waiting thread to become ready
64         notify();
65
66         System.err.println( Thread.currentThread().getName() +
67            " retrieving sharedInt value " + sharedInt );
68
69         return sharedInt;
70      }
71
72   }  // end class HoldIntegerSynchronized
```

Fig. 15.10 Class **HoldIntegerSynchronized** monitors access to a shared integer (part 2 of 2).

Methods **getSharedInt** and **setSharedInt** are implemented similarly. When the **ConsumeInteger** object invokes method **getSharedInt**, the calling thread acquires a lock on the **HoldIntegerSynchronized** object. The **while** structure at lines 46–57 tests the **writeable** variable. If **writeable** is **true** (i.e., there is nothing to consume), the thread invokes method **wait**. This places the **ConsumeInteger** thread object that called method **getSharedInt** into the waiting state for the **HoldIntegerSynchronized** object and releases the lock on it so other **synchronized** methods can be invoked on the object. The **ConsumeInteger** object remains in the waiting state until it is *notified* that it may proceed—at which point it enters the *ready* state and waits to be assigned a processor. When the **ConsumeInteger** object reenters the running state, the thread reacquires the lock on the **HoldIntegerSynchronized** object and the **getSharedInt** method continues executing in the **while** structure with the next statement after **wait**. There are no more statements, so the program tests the **while** condition again. If the condition is **false**, the program sets **writeable** to **true** to indicate that the shared memory is now empty and invokes method **notify**. If there are any waiting threads, one of those waiting threads enters the *ready* state, indicating that the thread can now attempt its task again (as soon as it is assigned a processor). The **notify** method returns immediately. Then, **getSharedInt** outputs a line to the command window indicating that the consumer is retrieving **sharedInt**, then returns the value of **sharedInt** to **getSharedInt**'s caller.

Study the output in Fig. 15.11. Observe that every integer produced is consumed once—no values are lost and no values are doubled. Also, the consumer cannot read a value until the producer produces a value.

```
1  // Fig. 15.11: SharedCell.java
2  // Show multiple threads modifying shared object.
3  public class SharedCell {
4
5     // execute application
6     public static void main( String args[] )
7     {
8        HoldIntegerSynchronized sharedObject =
9           new HoldIntegerSynchronized();
10
11       // create threads
12       ProduceInteger producer =
13          new ProduceInteger( sharedObject );
14       ConsumeInteger consumer =
15          new ConsumeInteger( sharedObject );
16
17       // start threads
18       producer.start();
19       consumer.start();
20    }
21
22 }  // end class SharedCell
```

```
ProduceInteger setting sharedInt to 1
ConsumeInteger retrieving sharedInt value 1
ProduceInteger setting sharedInt to 2
ConsumeInteger retrieving sharedInt value 2
ProduceInteger setting sharedInt to 3
ConsumeInteger retrieving sharedInt value 3
ProduceInteger setting sharedInt to 4
ConsumeInteger retrieving sharedInt value 4
ProduceInteger setting sharedInt to 5
ConsumeInteger retrieving sharedInt value 5
ProduceInteger setting sharedInt to 6
ConsumeInteger retrieving sharedInt value 6
ProduceInteger setting sharedInt to 7
ConsumeInteger retrieving sharedInt value 7
ProduceInteger setting sharedInt to 8
ConsumeInteger retrieving sharedInt value 8
ProduceInteger setting sharedInt to 9
ConsumeInteger retrieving sharedInt value 9
ProduceInteger setting sharedInt to 10
ProduceInteger finished producing values
Terminating ProduceInteger
ConsumeInteger retrieving sharedInt value 10
ConsumeInteger retrieved values totaling: 55
Terminating ConsumeInteger
```

Fig. 15.11 Threads modifying a shared object with synchronization.

15.8 Producer/Consumer Relationship: The Circular Buffer

The program of Fig. 15.8–Fig. 15.11 does access the shared data correctly, but it may not perform optimally. Because the threads are running asynchronously, we cannot predict their relative speeds. If the producer wants to produce faster than the consumer can consume, it cannot do so. To enable the producer to continue producing, we can use a circular buffer that has enough extra cells to handle the "extra" production. The program of Fig. 15.13–Fig. 15.16 demonstrates a producer and a consumer accessing a circular buffer (in this case, a shared array of five cells) with synchronization so that the consumer only consumes a value when there are one or more values in the array, and the producer only produces a value when there are one or more available cells in the array. This program is implemented as a windowed application that sends its output to a **`JTextArea`**. Class **`SharedCell`**'s constructor creates the **`HoldIntegerSynchronized`**, **`ProduceInteger`** and **`ConsumeInteger`** objects. The **`HoldIntegerSynchronized`** object **`sharedObject`**'s constructor receives a reference to a **`JTextArea`** object in which the program's output will appear.

This is the first program in which we use separate threads to modify the content displayed in Swing GUI components. The nature of multithreaded programming prevents the programmer from knowing exactly when a thread will execute. Swing components are not thread-safe—if multiple threads access a Swing GUI component, the results may not be correct. All interactions with Swing GUI components should be performed from one thread at a time. Normally, this thread is the *event-dispatch thread* (also known as the *event-handling thread*). Class ***`SwingUtilities`*** (package **`javax.swing`**) provides **`static`** method ***`invokeLater`*** to help with this process. Method **`invokeLater`** receives a **`Runnable`** argument. We will see in the next section that **`Runnable`** objects have a **`run`** method. In fact, class **`Thread`** implements interface **`Runnable`**, so all **`Thread`**s have a **`run`** method. The threads in this example pass objects of class **`UpdateThread`** (Fig. 15.13) to method **`invokeLater`**. Each **`UpdateThread`** object receives a reference to the **`JTextArea`** in which to append the output and the message to display. Method **`run`** of class **`UpdateThread`** appends the message to the **`JTextArea`**. When the program calls **`invokeLater`**, the GUI component update will be queued for execution in the event-dispatch thread. The **`run`** method will then be invoked as part of the event-dispatch thread, ensuring that the GUI component updates in a thread-safe manner.

Common Programming Error 15.3

Interactions with Swing GUI components that change or obtain property values of the components may have incorrect results if the interactions are performed from multiple threads.

Software Engineering Observation 15.2

*Use **`SwingUtilities`** **`static`** method **`invokeLater`** to ensure that all GUI interactions are performed from the event-dispatch thread.*

Class **`ProduceInteger`** (Fig. 15.13) has been modified slightly from the version presented in Fig. 15.8. The new version places its output in a **`JTextArea`**. **`ProduceInteger`** receives a reference to the **`JTextArea`** when the program calls the **`ProduceInteger`** constructor. Note the use of **`SwingUtilities`** method **`invokeLater`** in lines 42–44 to ensure that the GUI updates properly.

```
1  // Fig. 15.12: UpdateThread.java
2  // Class for updating JTextArea with output.
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class UpdateThread extends Thread {
8     private JTextArea outputArea;
9     private String messageToOutput;
10
11    // initialize outputArea and message
12    public UpdateThread( JTextArea output, String message )
13    {
14       outputArea = output;
15       messageToOutput = message;
16    }
17
18    // method called to update outputArea
19    public void run()
20    {
21       outputArea.append( messageToOutput );
22    }
23
24 }  // end class UpdateThread
```

Fig. 15.12 **UpdateThread** used by **SwingUtilities** method **invokeLater** to ensure GUI updates properly.

```
1  // Fig. 15.13: ProduceInteger.java
2  // Definition of threaded class ProduceInteger
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class ProduceInteger extends Thread {
8     private HoldIntegerSynchronized sharedObject;
9     private JTextArea outputArea;
10
11    // initialize ProduceInteger
12    public ProduceInteger( HoldIntegerSynchronized shared,
13       JTextArea output )
14    {
15       super( "ProduceInteger" );
16
17       sharedObject = shared;
18       outputArea = output;
19    }
20
21    // ProduceInteger thread loops 10 times and calls
22    // sharedObject's setSharedInt method each time
```

Fig. 15.13 Class **ProduceInteger** represents the producer in a producer/consumer relationship (part 1 of 2).

```
23     public void run()
24     {
25        for ( int count = 1; count <= 10; count++ ) {
26
27           // sleep for a random interval
28           // Note: Interval shortened purposely to fill buffer
29           try {
30              Thread.sleep( (int) ( Math.random() * 500 ) );
31           }
32
33           // process InterruptedException during sleep
34           catch( InterruptedException exception ) {
35              System.err.println( exception.toString() );
36           }
37
38           sharedObject.setSharedInt( count );
39        }
40
41        // update Swing GUI component
42        SwingUtilities.invokeLater( new UpdateThread( outputArea,
43           "\n" + getName() + " finished producing values" +
44           "\nTerminating " + getName() + "\n" ) );
45     }
46
47  }  // end class ProduceInteger
```

Fig. 15.13 Class **ProduceInteger** represents the producer in a producer/consumer relationship (part 2 of 2).

Class **ConsumeInteger** (Fig. 15.14) has been modified slightly from the version presented in Fig. 15.9. The new version places its output in a **JTextArea**. **ConsumeInteger** receives a reference to the **JTextArea** when the program calls the **ConsumeInteger** constructor. Note the use of **SwingUtilities** method **invokeLater** in lines 45–47 to ensure that the GUI updates properly.

```
1  // Fig. 15.14: ConsumeInteger.java
2  // Definition of threaded class ConsumeInteger
3
4  // Java extension packages
5  import javax.swing.*;
6
7  public class ConsumeInteger extends Thread {
8     private HoldIntegerSynchronized sharedObject;
9     private JTextArea outputArea;
10
11    // initialize ConsumeInteger
12    public ConsumeInteger( HoldIntegerSynchronized shared,
13       JTextArea output )
14    {
15       super( "ConsumeInteger" );
```

Fig. 15.14 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 1 of 2).

```
16
17          sharedObject = shared;
18          outputArea = output;
19       }
20
21       // ConsumeInteger thread loops until it receives 10
22       // from sharedObject's getSharedInt method
23       public void run()
24       {
25          int value, sum = 0;
26
27          do {
28
29             // sleep for a random interval
30             try {
31                Thread.sleep( (int) ( Math.random() * 3000 ) );
32             }
33
34             // process InterruptedException during sleep
35             catch( InterruptedException exception ) {
36                System.err.println( exception.toString() );
37             }
38
39             value = sharedObject.getSharedInt();
40             sum += value;
41
42          } while ( value != 10 );
43
44          // update Swing GUI component
45          SwingUtilities.invokeLater( new UpdateThread( outputArea,
46             "\n" + getName() + " retrieved values totaling: " +
47             sum + "\nTerminating " + getName() + "\n" ) );
48       }
49
50    }  // end class ConsumeInteger
```

Fig. 15.14 Class **ConsumeInteger** represents the consumer in a producer/consumer relationship (part 2 of 2).

Once again, the primary changes in this example are in the definition of class **HoldIntegerSynchronized** (Fig. 15.15). The class now contains six instance variables—**sharedInt** is a five-element integer array that is used as the circular buffer, **writeable** indicates if a producer can write into the circular buffer, **readable** indicates if a consumer can read from the circular buffer, **readLocation** indicates the current position from which the consumer can read the next value, **writeLocation** indicates the next location in which the producer can place a value and **outputArea** is the **JTextArea** used by the threads in this program to display output.

```
1  // Fig. 15.15: HoldIntegerSynchronized.java
2  // Definition of class HoldIntegerSynchronized that
```

Fig. 15.15 Class **HoldIntegerSynchronized** monitors access to a shared array of integers (part 1 of 5).

```
3  // uses thread synchronization to ensure that both
4  // threads access sharedInt at the proper times.
5
6  // Java core packages
7  import java.text.DecimalFormat;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class HoldIntegerSynchronized {
13
14    // array of shared locations
15    private int sharedInt[] = { -1, -1, -1, -1, -1 };
16
17    // variables to maintain buffer information
18    private boolean writeable = true;
19    private boolean readable = false;
20    private int readLocation = 0, writeLocation = 0;
21
22    // GUI component to display output
23    private JTextArea outputArea;
24
25    // initialize HoldIntegerSynchronized
26    public HoldIntegerSynchronized( JTextArea output )
27    {
28       outputArea = output;
29    }
30
31    // synchronized method allows only one thread at a time to
32    // invoke this method to set a value in a particular
33    // HoldIntegerSynchronized object
34    public synchronized void setSharedInt( int value )
35    {
36       while ( !writeable ) {
37
38          // thread that called this method must wait
39          try {
40
41             // update Swing GUI component
42             SwingUtilities.invokeLater( new UpdateThread(
43                outputArea, " WAITING TO PRODUCE " + value ) );
44
45             wait();
46          }
47
48          // process InterrupteException while thread waiting
49          catch ( InterruptedException exception ) {
50             System.err.println( exception.toString() );
51          }
52       }
53
```

Fig. 15.15 Class **HoldIntegerSynchronized** monitors access to a shared array of integers (part 2 of 5).

```
54          // place value in writeLocation
55          sharedInt[ writeLocation ] = value;
56
57          // indicate that consumer can read a value
58          readable = true;
59
60          // update Swing GUI component
61          SwingUtilities.invokeLater( new UpdateThread( outputArea,
62             "\nProduced " + value + " into cell " +
63             writeLocation ) );
64
65          // update writeLocation for future write operation
66          writeLocation = ( writeLocation + 1 ) % 5;
67
68          // update Swing GUI component
69          SwingUtilities.invokeLater( new UpdateThread( outputArea,
70             "\twrite " + writeLocation + "\tread " +
71             readLocation ) );
72
73          displayBuffer( outputArea, sharedInt );
74
75          // test if buffer is full
76          if ( writeLocation == readLocation ) {
77             writeable = false;
78
79             // update Swing GUI component
80             SwingUtilities.invokeLater( new UpdateThread( outputArea,
81                "\nBUFFER FULL" ) );
82          }
83
84          // tell a waiting thread to become ready
85          notify();
86
87       }  // end method setSharedInt
88
89       // synchronized method allows only one thread at a time to
90       // invoke this method to get a value from a particular
91       // HoldIntegerSynchronized object
92       public synchronized int getSharedInt()
93       {
94          int value;
95
96          while ( !readable ) {
97
98             // thread that called this method must wait
99             try {
100
101               // update Swing GUI component
102               SwingUtilities.invokeLater( new UpdateThread(
103                  outputArea, " WAITING TO CONSUME" ) );
104
```

Fig. 15.15 Class **HoldIntegerSynchronized** monitors access to a shared array of integers (part 3 of 5).

```
105             wait();
106          }
107
108          // process InterrupteException while thread waiting
109          catch ( InterruptedException exception ) {
110             System.err.println( exception.toString() );
111          }
112       }
113
114       // indicate that producer can write a value
115       writeable = true;
116
117       // obtain value at current readLocation
118       value = sharedInt[ readLocation ];
119
120       // update Swing GUI component
121       SwingUtilities.invokeLater( new UpdateThread( outputArea,
122          "\nConsumed " + value + " from cell " +
123          readLocation ) );
124
125       // update read location for future read operation
126       readLocation = ( readLocation + 1 ) % 5;
127
128       // update Swing GUI component
129       SwingUtilities.invokeLater( new UpdateThread( outputArea,
130          "\twrite " + writeLocation + "\tread " +
131          readLocation ) );
132
133       displayBuffer( outputArea, sharedInt );
134
135       // test if buffer is empty
136       if ( readLocation == writeLocation ) {
137          readable = false;
138
139          // update Swing GUI component
140          SwingUtilities.invokeLater( new UpdateThread(
141             outputArea, "\nBUFFER EMPTY" ) );
142       }
143
144       // tell a waiting thread to become ready
145       notify();
146
147       return value;
148
149    }  // end method getSharedInt
150
151    // diplay contents of shared buffer
152    public void displayBuffer( JTextArea outputArea,
153       int buffer[] )
154    {
155       DecimalFormat formatNumber = new DecimalFormat( " #;-#" );
156       StringBuffer outputBuffer = new StringBuffer();
```

Fig. 15.15 Class **HoldIntegerSynchronized** monitors access to a shared array of integers (part 4 of 5).

```
157
158         // place buffer elements in outputBuffer
159         for ( int count = 0; count < buffer.length; count++ )
160            outputBuffer.append(
161               " " + formatNumber.format( buffer[ count ] ) );
162
163         // update Swing GUI component
164         SwingUtilities.invokeLater( new UpdateThread( outputArea,
165            "\tbuffer: " + outputBuffer ) );
166      }
167
168   }  // end class HoldIntegerSynchronized
```

Fig. 15.15 Class **HoldIntegerSynchronized** monitors access to a shared array of integers (part 5 of 5).

Method **setSharedInt** (lines 34–87) performs the same tasks as it did in Fig. 15.10, with a few modifications. When execution continues at line 55 after the **while** loop, **setSharedInt** places the produced value in the circular buffer at location **writeLocation**. Next, **readable** is set to **true** (line 58), because there is at least one value in the buffer that the client can read. Lines 61–63 use **SwingUtilities** method **invokeLater** to append the value produced and the cell where the value was placed to the **JTextArea** (method **run** of class **UpdateThread** performs the actual append operation). Then, line 66 updates **writeLocation** for the next call to **setSharedInt**. The output continues with the current **writeLocation** and **readLocation** values and the values in the circular buffer (lines 69–73). If the **writeLocation** is equal to the **readLocation**, the circular buffer is currently full, so **writeable** is set to **false** (line 77) and the program displays the string **BUFFER FULL** (lines 80–81). Finally, line 85 invokes method **notify** to indicate that a waiting thread should move to the ready state.

Method **getSharedInt** (lines 92–149) also performs the same tasks in this example as it did in Fig. 15.10, with a few minor modifications. When execution continues at line 115 after the **while** loop, **writeable** is set to **true** because there will be at least one open position in the buffer in which the producer can place a value. Next, line 118 assigns **value** the value at **readLocation** in the circular buffer. Lines 121–123 append to the **JTextArea** the value consumed and the cell from which the value was read. Then, line 126 updates **readLocation** for the next call to method **getSharedInt**. Lines 129–131 continue the output in the **JTextArea** with the current **writeLocation** and **readLocation** values and the current values in the circular buffer. If the **readLocation** is equal to the **writeLocation**, the circular buffer is currently empty, so **readable** is set to **false** (line 137), and lines 140–141 display the string **BUFFER EMPTY**. Finally, line 145 invokes method **notify** to place the next waiting thread into the *ready* state, and line 147 returns the retrieved value to the calling method.

In this version of the program, the outputs include the current **writeLocation** and **readLocation** values and the current contents of the buffer **sharedInt**. The elements of the **sharedInt** array were initialized to –1 for output purposes so that you can see each value inserted in the buffer. Notice that after the program places the fifth value in the fifth element of the buffer, the program inserts the sixth value at the beginning of the array—thus providing the *circular buffer* effect. Method **displayBuffer** (lines 152–166) uses

a **DecimalFormat** object to format the contents of the array **buffer**. The format control string **" #;-#"** indicates a positive number format and a negative number format—the formats are separated by a semicolon (**;**). The format specifies that positive values should be preceded by a space and negative values should be preceded by a minus sign.

```
1  // Fig. 15.16: SharedCell.java
2  // Show multiple threads modifying shared object.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.text.DecimalFormat;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class SharedCell extends JFrame {
13
14    // set up GUI
15    public SharedCell()
16    {
17       super( "Demonstrating Thread Synchronization" );
18
19       JTextArea outputArea = new JTextArea( 20, 30 );
20       getContentPane().add( new JScrollPane( outputArea ) );
21
22       setSize( 500, 500 );
23       show();
24
25       // set up threads
26       HoldIntegerSynchronized sharedObject =
27          new HoldIntegerSynchronized( outputArea );
28
29       ProduceInteger producer =
30          new ProduceInteger( sharedObject, outputArea );
31
32       ConsumeInteger consumer =
33          new ConsumeInteger( sharedObject, outputArea );
34
35       // start threads
36       producer.start();
37       consumer.start();
38    }
39
40    // execute application
41    public static void main( String args[] )
42    {
43       SharedCell application = new SharedCell();
44
45       application.setDefaultCloseOperation(
46          JFrame.EXIT_ON_CLOSE );
47    }
```

Fig. 15.16 Threads modifying a shared array of cells (part 1 of 2).

```
48
49 } // end class SharedCell
```

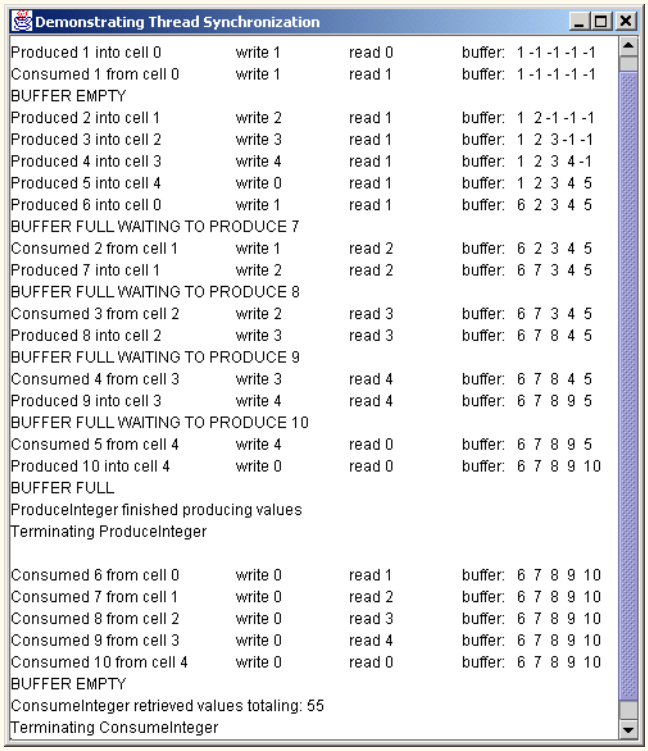


Fig. 15.16 Threads modifying a shared array of cells (part 2 of 2).

15.9 Daemon Threads

A daemon thread is a thread that runs for the benefit of other threads. Unlike conventional user threads (i.e., any non-daemon thread in a program), daemon threads do not prevent a program from terminating. The garbage collector is a daemon thread. Nondaemon threads are conventional user threads or threads such as the event-dispatch thread used to process GUI events. We designate a thread as a daemon with the method call

```
setDaemon( true );
```

A **`false`** argument means that the thread is not a daemon thread. A program can include a mixture of daemon threads and nondaemon threads. When only daemon threads remain in a program, the program exits. If a thread is to be a daemon, it must be set as such before its **`start`** method is called or an **`IllegalThreadStateException`** is thrown. Method **`isDaemon`** returns **`true`** if a thread is a daemon thread and **`false`** otherwise.

Common Programming Error 15.4

Starting a thread, then attempting to make the thread a daemon thread, causes an ***`IllegalThreadStateException`***.

Software Engineering Observation 15.3

The event-dispatch thread is an infinite loop and is not a daemon thread. As such, the event-dispatch thread will not terminate in a windowed application until the application calls ***System*** *method* ***exit****.*

Good Programming Practice 15.1

Do not assign critical tasks to a daemon thread. They are terminated without warning, which may prevent those tasks from completing properly.

15.10 `Runnable` Interface

Until now, we extended class **`Thread`** to create new classes that support multithreading. We overrode the **`run`** method to specify the tasks to be performed concurrently. However, if we want multithreading support in a class that already extends a class other than **`Thread`**, we must implement the ***`Runnable`*** *interface* in that class, because Java does not allow a class to extend more than one class at a time. Class **`Thread`** itself implements the **`Runnable`** interface (package **`java.lang`**) as expressed in the class header

```
public class Thread extends Object implements Runnable
```

Implementing the **`Runnable`** interface in a class enables a program to manipulate objects of that class as **`Runnable`** objects. As with deriving from the **`Thread`** class, the code that controls the thread is placed in method **`run`**.

A program that uses a **`Runnable`** object creates a **`Thread`** object and associates the Runnable object with that **`Thread`**. Class **`Thread`** provides four constructors that can receive references to **`Runnable`** objects as arguments. For example, the constructor

```
public Thread( Runnable runnableObject )
```

registers method **`run`** of **`runnableObject`** as the method to be invoked when the thread begins execution. The constructor

```
public Thread( Runnable runnableObject, String threadName )
```

constructs a **`Thread`** with the name **`threadName`** and registers method **`run`** of its **`runnableObject`** argument as the method to be invoked when the thread begins execution. As always, the thread object's **`start`** method must be called to begin the thread's execution.

Figure 15.17 demonstrates an applet with a **`private`** inner class and an anonymous inner class that each implement interface **`Runnable`**. The example also demonstrates how to suspend a thread (i.e., temporarily prevent it from executing), how to resume a suspended thread and how to terminate a thread that executes until a condition becomes false. Each of these techniques is important because **`Thread`** methods **`suspend`**, **`resume`** and **`stop`** were deprecated (i.e., they should no longer be used in Java programs) with the introduction of the Java 2 Platform. Because these methods are deprecated, we must code our own mechanisms for suspending, resuming and stopping threads. As we will demonstrate, these mechanisms rely on **`synchronized`** blocks of code, loops and **`boolean`** flag variables.

The applet class **RandomCharacters** displays three **JLabel**s and three **JCheckBox**es. A separate thread of execution is associated with each **JLabel** and button pair. Each thread randomly displays letters from the alphabet in its corresponding **JLabel** object. The applet defines the **String alphabet** (line 16) containing the letters from A to Z. This string is shared among the three threads. The applet's **start** method (lines 52–65) instantiates three **Thread** objects (lines 59–60) and initializes each with an instance of class **RunnableObject**, which implements interface **Runnable**. Line 63 invokes the **Thread** class **start** method on each **Thread**, placing the threads in the *ready* state.

Class **RunnableObject** is defined at lines 115–185. Its **run** method (line 120) defines two local variables. Line 123 uses **static** method **currentThread** of class **Thread** to determine the currently executing **Thread** object. Line 125 calls the applet's utility method **getIndex** (defined at lines 68–76) to determine the index of the currently executing thread in the array **threads**. The current thread displays a random character in the **JLabel** object with the same **index** in array **outputs**.

```
1  // Fig. 15.17: RandomCharacters.java
2  // Demonstrating the Runnable interface.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class RandomCharacters extends JApplet
12    implements ActionListener {
13
14    // declare variables used by applet and
15    // inner class RunnableObject
16    private String alphabet = "ABCDEFGHIJKLMNOPQRSTUVWXYZ";
17    private final static int SIZE = 3;
18
19    private JLabel outputs[];
20    private JCheckBox checkboxes[];
21
22    private Thread threads[];
23    private boolean suspended[];
24
25    // set up GUI and arrays
26    public void init()
27    {
28       outputs = new JLabel[ SIZE ];
29       checkboxes = new JCheckBox[ SIZE ];
30       threads = new Thread[ SIZE ];
31       suspended = new boolean[ SIZE ];
32
33       Container container = getContentPane();
34       container.setLayout( new GridLayout( SIZE, 2, 5, 5 ) );
```

Fig. 15.17 Demonstrating the **Runnable** interface, suspending threads and resuming threads (part 1 of 5).

```
35
36          // create GUI components, register listeners and attach
37          // components to content pane
38          for ( int count = 0; count < SIZE; count++ ) {
39             outputs[ count ] = new JLabel();
40             outputs[ count ].setBackground( Color.green );
41             outputs[ count ].setOpaque( true );
42             container.add( outputs[ count ] );
43
44             checkboxes[ count ] = new JCheckBox( "Suspended" );
45             checkboxes[ count ].addActionListener( this );
46             container.add( checkboxes[ count ] );
47          }
48       }
49
50       // Create and start threads. This method called after init
51       // and when user revists Web page containing this applet
52       public void start()
53       {
54          // create threads and start every time start is called
55          for ( int count = 0; count < threads.length; count++ ) {
56
57             // create Thread and initialize it with object that
58             // implements Runnable
59             threads[ count ] = new Thread( new RunnableObject(),
60                "Thread " + ( count + 1 ) );
61
62             // begin executing Thread
63             threads[ count ].start();
64          }
65       }
66
67       // determine thread location in threads array
68       private int getIndex( Thread current )
69       {
70          for ( int count = 0; count < threads.length; count++ )
71
72             if ( current == threads[ count ] )
73                return count;
74
75          return -1;
76       }
77
78       // called when user switches Web pages; stops all threads
79       public synchronized void stop()
80       {
81          // Indicate that each thread should terminate. Setting
82          // these references to null causes each thread's run
83          // method to complete execution.
84          for ( int count = 0; count < threads.length; count++ )
85             threads[ count ] = null;
86
```

Fig. 15.17 Demonstrating the **Runnable** interface, suspending threads and resuming threads (part 2 of 5).

```
87          // make all waiting threads ready to execute, so they
88          // can terminate themselves
89          notifyAll();
90       }
91
92       // handle button events
93       public synchronized void actionPerformed( ActionEvent event )
94       {
95          for ( int count = 0; count < checkboxes.length; count++ ) {
96
97             if ( event.getSource() == checkboxes[ count ] ) {
98                suspended[ count ] = !suspended[ count ];
99
100               // change label color on suspend/resume
101               outputs[ count ].setBackground(
102                  !suspended[ count ] ? Color.green : Color.red );
103
104               // if thread resumed, make sure it starts executing
105               if ( !suspended[ count ] )
106                  notifyAll();
107
108               return;
109            }
110         }
111      }
112
113      // private inner class that implements Runnable so objects
114      // of this class can control threads
115      private class RunnableObject implements Runnable {
116
117         // Place random characters in GUI. Local variables
118         // currentThread and index are declared final so
119         // they can be used in an anonymous inner class.
120         public void run()
121         {
122            // get reference to executing thread
123            final Thread currentThread = Thread.currentThread();
124
125            // determine thread's position in array
126            final int index = getIndex( currentThread );
127
128            // loop condition determines when thread should stop
129            while ( threads[ index ] == currentThread ) {
130
131               // sleep from 0 to 1 second
132               try {
133                  Thread.sleep( ( int ) ( Math.random() * 1000 ) );
134
135                  // Determine whether thread should suspend
136                  // execution. Use applet as monitor.
137                  synchronized( RandomCharacters.this ) {
138
```

Fig. 15.17 Demonstrating the **Runnable** interface, suspending threads and resuming threads (part 3 of 5).

```
139                   while ( suspended[ index ] &&
140                      threads[ index ] == currentThread ) {
141
142                      // Temporarily stop thread execution. Use
143                      // applet as monitor.
144                      RandomCharacters.this.wait();
145                   }
146
147                }  // end synchronized block
148             }
149
150             // process InterruptedExceptions during sleep or wait
151             catch ( InterruptedException interruptedException ) {
152                System.err.println( "sleep interrupted" );
153             }
154
155             // display character on corresponding label
156             SwingUtilities.invokeLater(
157
158                // anonymous inner class used by SwingUtilities
159                // method invokeLater to ensure GUI
160                // updates properly
161                new Runnable() {
162
163                   // updates Swing GUI component
164                   public void run()
165                   {
166                      // pick random character
167                      char displayChar = alphabet.charAt(
168                         ( int ) ( Math.random() * 26 ) );
169
170                      outputs[ index ].setText(
171                         currentThread.getName() + ": " +
172                         displayChar );
173                   }
174
175                }  // end anonymous inner class
176
177             ); // end call to SwingUtilities.invokeLater
178
179          }  // end while
180
181          System.err.println(
182             currentThread.getName() + " terminating" );
183       }
184
185    }  // end private inner class RunnableObject
186
187 }  // end class RandomCharacters
```

Fig. 15.17 Demonstrating the **`Runnable`** interface, suspending threads and resuming threads (part 4 of 5).

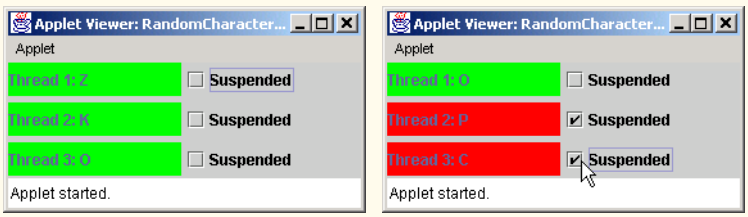


Fig. 15.17 Demonstrating the **`Runnable`** interface, suspending threads and resuming threads (part 5 of 5).

The **`while`** loop at lines 129–179 continues to execute as long as the specified **`Thread`** reference is equal to the reference to the currently executing thread (**`currentThread`**). In each iteration of the loop, the thread sleeps for a random interval from 0 to 1 second.

When the user clicks the **`JCheckBox`** to the right of a particular **`JLabel`**, the corresponding **`Thread`** should be *suspended* (temporarily prevented from executing) or *resumed* (allowed to continue executing). In previous versions of Java, methods **`suspend`** and **`resume`** of class **`Thread`** were provided to suspend and resume a thread's execution. These methods are now deprecated (i.e., they should no longer be used) because they introduce the possibility of deadlock in a program if they are not used correctly. Suspending and resuming of a thread can be implemented using thread synchronization and methods **`wait`** and **`notify`** of class **`Object`**. Lines 137–147 define a ***`synchronized`*** *block* of code (also called a ***`synchronized`*** *statement*) that helps suspend the currently executing **`Thread`**. When the **`Thread`** reaches the **`synchronized`** block, the applet object (referenced with **`RandomCharacters.this`**) is locked and the **`while`** structure tests **`suspended[ index ]`** to determine if the **`Thread`** should be suspended (i.e., **`true`**). If so, line 144 invokes method **`wait`** on the applet object to place the **`Thread`** in the waiting state. [Note the use of **`RandomCharacters.this`** to access the applet class's **`this`** reference from the private inner class **`RunnableObject`**.] When the **`Thread`** should resume, the program tells all waiting threads to become ready to execute (we will discuss this shortly). However, only the resumed thread will get a chance to execute. The other suspended thread(s) will reenter the waiting state. Lines 156–177 use **`SwingUtilities`** method **`invokeLater`** to update the **`JLabel`** for the appropriate thread. This example uses an anonymous inner class to implement the **`Runnable`** interface (lines 161–175) and passes the anonymous inner class object to **`invokeLater`**. Lines 167–168 choose a random character from the **`alphabet`** string. Lines 170–172 display the character on the appropriate **`JLabel`** object.

Software Engineering Observation 15.4

An inner class can reference its outer class's ***`this`*** *reference by preceding the* ***`this`*** *reference with the outer class name and a dot operator.*

If the user clicks the **Suspended** check box next to a particular **`JLabel`**, the program invokes method **`actionPerformed`** (lines 93–111). The method determines which checkbox received the event. Using the index of that checkbox in array **`outputs`**, line 98 toggles the corresponding **`boolean`** in array **`suspended`**. Lines 101–102 set the background color of the **`JLabel`** to red if the thread is being suspended and green if the thread

is being resumed. If the appropriate **boolean** variable is **false**, the program calls method **notifyAll** (line 106) to move all waiting threads into the ready state and prepare them to resume execution. When each thread is dispatched to the processor to resume execution, the **while** condition at lines 139–140 in the **run** method fails for the resumed thread and the loop terminates. Execution of the **run** method then continues from line 156. For any other threads that became ready, but still are suspended, the condition at lines 139–140 remains true and the threads reenter the waiting state.

The applet's **stop** method (lines 79–90) is provided to stop all three threads if the user leaves the Web page on which this applet resides (you can simulate this by selecting **Stop** from the **appletviewer**'s **Applet** menu). The **for** loop at lines 84–85 sets each **Thread** reference in array **threads** to **null**. Line 89 invokes **Object** method **notifyAll** to ensure that all waiting threads get ready to execute. When the program encounters the **while** loop condition at line 129 for each thread, the condition fails and the **run** method terminates. Thus, each thread dies. If the user returns to the Web page, the applet container calls the applet's **start** method to instantiate and start three new threads.

Performance Tip 15.5

Stopping applet threads when leaving a Web page is a polite programming practice because it prevents your applet from using processor time (which can reduce performance) on the browser's machine when the applet is not being viewed. The threads can be restarted from the applet's **start** *method, which is invoked by the browser when the Web page is revisited by the user.*

15.11 Thread Groups

Sometimes it is useful to identify various threads as belonging to a *thread group*; class **ThreadGroup** contains methods for creating and manipulating thread groups. At constructor time, the group is given a unique name via a **String** argument.

The threads in a thread group can be manipulated as a group. It may, for example, be desirable to **interrupt** all the threads in a group. A thread group can be the *parent thread group* to a *child thread group*. Method calls sent to a parent thread group are also sent to all the threads in that parent's child thread groups.

Class **ThreadGroup** provides two constructors. The constructor

```
public ThreadGroup( String stringName )
```

constructs a **ThreadGroup** with name **stringName**. The constructor

```
public ThreadGroup( ThreadGroup parentThreadGroup,
   String stringName )
```

constructs a child **ThreadGroup** of **parentThreadGroup** called **stringName**.

Class **Thread** provides three constructors that enable the programmer to instantiate a **Thread** and associate it with a **ThreadGroup**. The constructor

```
public Thread( ThreadGroup threadGroup, String stringName )
```

constructs a **Thread** that belongs to **threadGroup** and has the name **stringName**. This constructor is normally invoked for derived classes of **Thread** whose objects should be associated with a **ThreadGroup**.

The constructor

```
public Thread( ThreadGroup threadGroup,
   Runnable runnableObject )
```

constructs a **Thread** that belongs to **threadGroup** and that invokes the **run** method of **runnableObject** when the thread is assigned a processor to begin execution.

The constructor

```
public Thread( ThreadGroup threadGroup,
   Runnable runnableObject, String stringName )
```

constructs a **Thread** that belongs to **threadGroup** and that invokes the **run** method of **runnableObject** when the thread is assigned a processor to begin execution. The name of this **Thread** is indicated by **stringName**.

Class **ThreadGroup** contains many methods for processing groups of threads. Some of these methods are summarized here. For more information on these methods, see the Java API documentation.

1. Method **activeCount** reports the number of active threads in a thread group plus the number of active threads in all its child thread groups.
2. Method **enumerate** has four versions. Two versions copy into an array of **Thread** references the active threads in the **ThreadGroup** (one of these also allows you to recursively get copies of all the active threads in child **ThreadGroup**). Two versions copy into an array of **ThreadGroup** references the active child thread groups in the **ThreadGroup** (one of these also allows you to recursively get copies of all the active thread groups in all the child **ThreadGroup**s).
3. Method **getMaxPriority** returns the maximum priority of a **ThreadGroup**. Method **setMaxPriority** sets a new maximum priority for a **ThreadGroup**.
4. Method **getName** returns as a **String** the **ThreadGroup**'s name.
5. Method **getParent** determines the parent of a thread group.
6. Method **parentOf** returns **true** if the **ThreadGroup** to which the message is sent is the parent of, or the same as, the **ThreadGroup** supplied as an argument and returns **false** otherwise.

Testing and Debugging Tip 15.5

*Method **list** lists the **ThreadGroup**. This can help in debugging.*

15.12 (Optional Case Study) Thinking About Objects: Multithreading

Real-world objects perform their operations independently of one another and concurrently (in parallel). As you learned in this chapter, Java is a multithreaded programming language that facilitates the implementation of concurrent activities. The UML also contains support for designing concurrent models, as we will see shortly. In this section, we discuss how our simulation benefits from multithreading.

In "Thinking About Objects" Section 10.22, we encountered a problem with the collaboration diagram of Fig. 10.26—the **waitingPassenger** (the **Person** waiting to ride the **Elevator**) always enters the **Elevator** before the **ridingPassenger** (the **Person** riding the **Elevator**) exits. Proper use of multithreading in Java avoids this problem by guaranteeing that the **waitingPassenger** must wait for the **ridingPassenger** to exit the **Elevator**—as would happen in real life. In our collaboration diagrams, objects pass messages to other objects by calling methods of those other objects—a sending object may proceed only after a method returns. Java refers to such a message pass as a *synchronous call*. However, the synchronous call is not *synchronized*, because several objects may access the method at the same time—the synchronous call cannot guarantee exclusivity to one object. This poses a problem when we model our elevator simulation, because according to Fig. 10.26, the **waitingPassenger** and the **ridingPassenger** may occupy the **Elevator** at the same time, which violates the "capacity-of-one" requirement specified in the problem statement. In this section, we use a **synchronized** method to guarantee that only one **Person** may occupy the **Elevator** at a time.

Threads, Active Classes and Synchronized Methods

Java uses threads—flows of program control independent of other flows—to represent independent, concurrent activities. The UML provides the notion of an *active class* to represent a thread. Classes **Elevator** and **Person** are active classes (threads), because their objects must be able to operate concurrently and independently of one another and of other objects in the system. For example, the **Elevator** must be able to move between **Floor**s while a **Person** is walking on a **Floor**. Figure 15.8 updates the collaboration diagram of Fig. 10.26 to support active classes, which are denoted by a thick black border in the diagram. To ensure that **Person**s enter and exit the **Elevator** in the proper order, we require a specific order in which to send messages—the **Elevator** must send message **3.3.1** (**ridingPassenger** exits) before sending message **3.2.1.1** (**waitingPassenger** enters the **Elevator**). The UML provides a notation to allow synchronization in collaboration diagrams—if we have two messages **A** and **B**, the notation **B/A** indicates that message **A** must wait for **B** to complete before message **A** occurs. For example, the **3.3.1/3.2.1.1** notation before the **enterElevator** message indicates that **waitingPassenger** must wait for **ridingPassenger** to exit the **Elevator** (message **3.3.1**) before entering (message **3.2.1.1**).

Software Engineering Observation 15.5

Messages in collaboration diagrams must complete in order (e.g., message 3.1 must complete before issuing message 3.2). However, messages between active classes may specify different ordering as necessary to guarantee synchronization between certain messages.

A **Person** must synchronize with the **Elevator** when traveling to guarantee that only one **Person** occupies the **Elevator** at a time. In Fig. 15.8, we include the **ride** message (**3.2.1.2**) to represent the **Person** riding the **Elevator** to the other **Floor**. The {concurrent} keyword placed after the **ride** message indicates that method **ride** is **synchronized** when we implement our design in Java. The **Elevator** contains method **ride** for the **Person** to allow the synchronization.

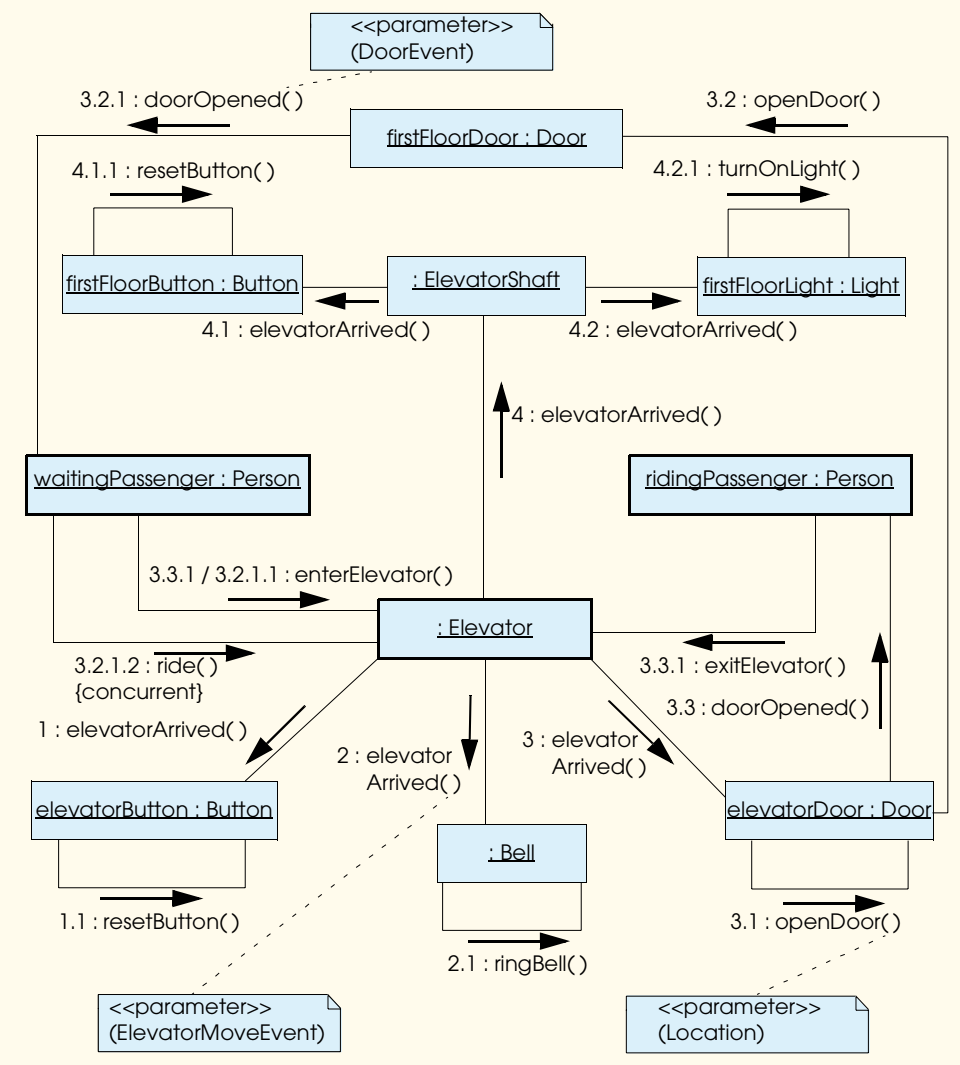


Fig. 15.8 Modified collaboration diagram with active classes for passengers entering and exiting the **`Elevator`**.

```
public synchronized void ride()
{
   try {
      Thread.sleep( maxTravelTime );
   }

   catch ( InterruptedException interruptedException ) {
      // method doorOpened in Person interrupts method sleep;
      // Person has finished riding Elevator
   }
}
```

Method **ride** guarantees that only one **Person** may ride the **Elevator** at a time—as described in Section 15.5, only one **synchronized** method may be active on an object at once, so all other **Person** threads attempting to invoke **ride** must wait for the current thread to exit method **ride**.

Method **ride** invokes **static** method **sleep** of class **Thread** to put the **Person** thread into the **sleep** state, which represents the **Person** waiting for the ride to complete. We must specify the maximum amount of time that a **Person** will wait for the **Elevator** to complete traveling—however, there is no such information specified in the problem statement. We introduce a new attribute that represents this time—**maxTravelTime**, to which we arbitrarily assign a value of **10** minutes (i.e., a **Person** will wait **10** minutes for the travel to complete). Attribute **maxTravelTime** is a safeguard in case the **Elevator**—for whatever reason—never reaches the other **Floor**. The **Person** should never have to wait this long—if the **Person** waits **10** minutes, then the **Elevator** is broken, and we assume that our **Person** crawls out of the **Elevator** and exits the simulation.

Software Engineering Observation 15.6

In a software-development process, the analysis phase yields a requirements document (e.g., our problem statement). As we continue the design and implementation phase, we discover additional issues that were not apparent to us at the analysis phase. As designers, we must anticipate these issues and deal with them accordingly.

Software Engineering Observation 15.7

One false assumption to make is that the system requirements remain stable (i.e., they provide all information necessary to build the system) throughout the analysis and design phases. In large systems that have long implementation phases, requirements can, and often do, change to accommodate those issues that were not apparent during analysis.

If our **Elevator** works correctly, the **Elevator** travels for five seconds—specifically, invoking method **sleep** halts the **Elevator**'s thread for five seconds to simulate the travel. When the **Elevator** thread awakens, it sends **elevatorArrived** events as described in Section 10.22. The **elevatorDoor** receives this event and invokes method **doorOpened** (message **3.3**) of the **ridingPassenger**, as in:

```
public void doorOpened( DoorEvent doorEvent )
{
   // set Person on Floor where Door opened
   setLocation( doorEvent.getLocation() );

   // interrupt Person's sleep method in run method and
   // Elevator's ride method
   interrupt();
}
```

Method **doorOpened** sets the **ridingPassenger**'s **Location** to the **Floor** at which the **Elevator** arrived, then calls the **ridingPassenger** thread's **interrupt** method. The **interrupt** method terminates the **sleep** method invoked in method **ride**, method **ride** terminates, and the **ridingPassenger** leaves the **Elevator**, then exits the simulation. When the **ridingPassenger** exits the **Elevator**, the **ridingPassenger** releases the monitor on the **Elevator** object, which allows the **waitingPassenger** to invoke the **ride** method and obtain the monitor. Now, the **waitingPassenger** may invoke method **ride** to ride the **Elevator**.

The **ridingPassenger** does not need to send the **exitElevator** message (message **3.3.1**) to the **Elevator**, because the **waitingPassenger** cannot invoke **ride** until the **ridingPassenger** releases the **Elevator**'s monitor—the **ridingPassenger** releases the monitor when the **ridingPassenger** thread exits method **ride** after calling its **interrupt** method. Therefore, the **Person** thread's **interrupt** method is equivalent to the **exitElevator** method (except that the **Person** sends itself the **interrupt** message), and we can substitute method **interrupt** for method **exitElevator**. Also, we can combine methods **ride** and **enterElevator** to handle both entering and riding the **Elevator**—our system needs only method **ride**, which allows a **Person** to obtain a monitor on the **Elevator**. As we implement our model in Appendix H, we use our collaboration diagram to help generate code in Java—however, we will make subtle "Java-specific" adjustments to our code to guarantee that the **Person**s enter and exit the **Elevator** correctly.

Sequence Diagrams

We now present the other type of interaction diagram, called a *sequence diagram*. Like the collaboration diagram, the sequence diagram shows interactions among objects; however, the sequence diagram emphasizes how messages are sent between objects *over time*. Both diagrams model interactions in a system. Collaboration diagrams emphasize what objects interact in a system, and sequence diagrams emphasize when these interactions occur.

Figure 15.9 is the sequence diagram for a **Person** changing floors. A rectangle enclosing the name of an object represents that object. We write object names in sequence diagrams using the same convention we have been using with collaboration diagrams. The dotted line extending down from an object's rectangle is that object's *lifeline*, which represents the progression of time. Actions occur along an object's lifeline in chronological order from top to bottom—an action near the top of a lifeline happens before an action near the bottom. We provide several notes in this diagram to clarify where the **Person** exists in the simulation. Note that the diagram includes several dashed arrows. These arrows represent "return messages," or the return of control to the sending object. Every message ultimately yields a return message. Showing return messages is not mandatory in a sequence diagram—we show return messages for clarity.

Message passing in sequence diagrams is similar to that in collaboration diagrams. An arrow extending from the object sending the message to the object receiving the message represents a message between two objects. The arrowhead points to the rectangle on the receiving object's lifeline. As previously mentioned, when an object returns control, a return message—represented as a dashed line with an arrowhead—extends from the object returning control to the object that initially sent the message.

The sequence in Fig. 15.9 begins when a **Person** presses a **Button** on a **Floor** by sending message **pressButton** to that **Button**. The **Button** then requests the **Elevator** by sending message **requestElevator** to the **Elevator**.

The **Person** must wait for the **Elevator** to process this message before continuing. However, the **Person** does not need to wait for the **Elevator**'s arrival before proceeding with other actions. In our simulation, we force the **Person** to wait, but we could have had the **Person** perform other actions, such as read a newspaper, sway back and forth or place a call on a cell phone as the **Elevator** travels to the **Floor** of the **Person**.

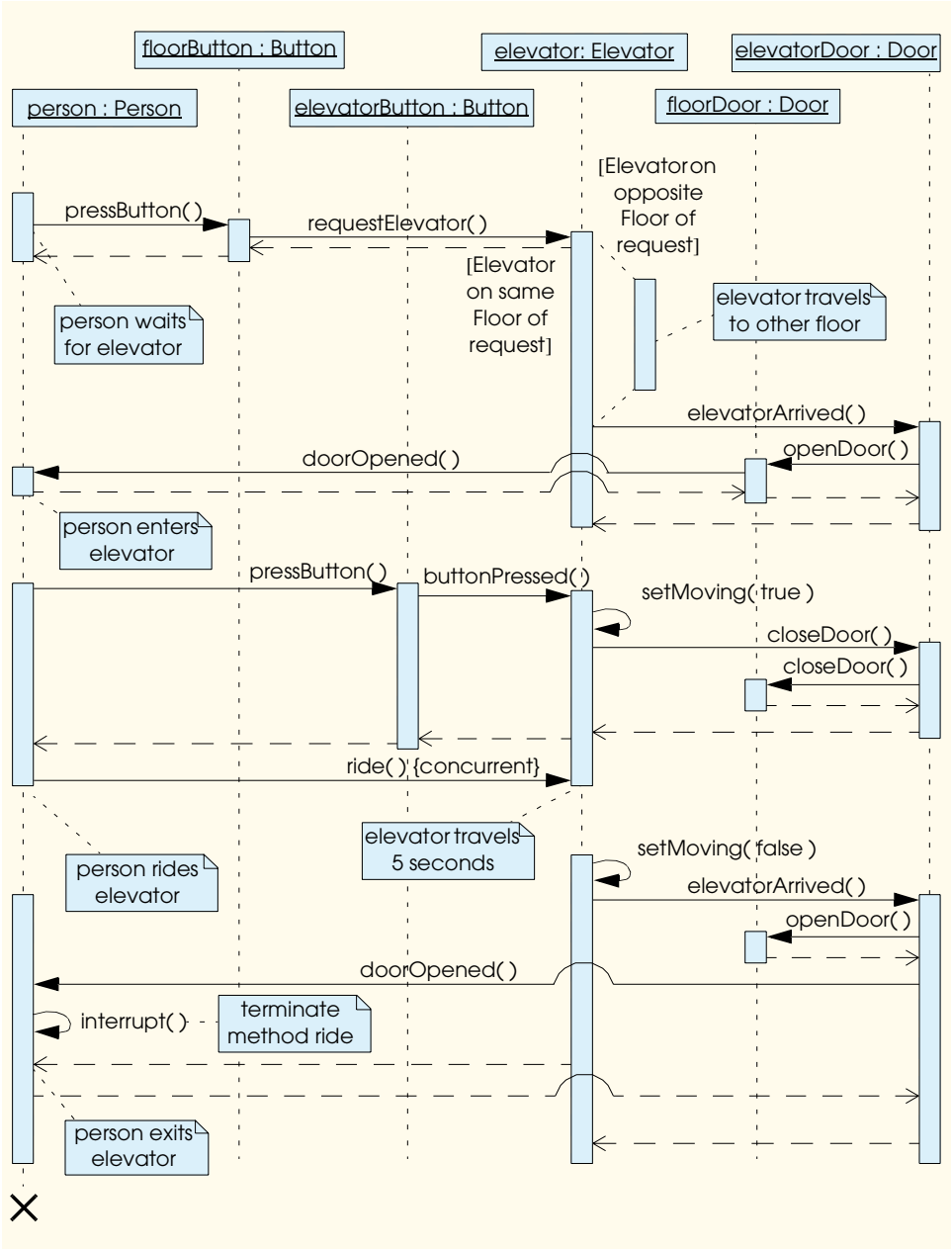


Fig. 15.9 Sequence diagram for a single **`Person`** changing floors in system.

Note the split in flow for the **`Elevator`** after being requested; the flow of execution depends on which **`Floor`** generated the request. If the **`Elevator`** is on a different **`Floor`**

than the request, the **Elevator** must move to the **Floor** on which the **Person** is waiting. To save space, the note informing that the **Elevator** moves to the other **Floor** represents this sequence (We will construct this sequence momentarily when we discuss how the **Person** rides the **Elevator** to the other **Floor**.) When the **Elevator** travels to the other **Floor**, the branched sequence merges with the original sequence in the **Elevator**'s lifeline, and the **elevatorDoor** sends an **elevatorArrived** message to the **elevatorDoor** upon arrival.

If the **Elevator** is on the same **Floor** as the request, the **elevatorDoor** immediately sends an **elevatorArrived** message to the **elevatorDoor** upon arrival. The **elevatorDoor** receives the arrival message and opens the **Door** on the arrival **Floor**. This door sends a **doorOpened** message to the **Person**—that **Person** then enters the **Elevator**.

The **Person** then presses the **elevatorButton**, which sends a **buttonPressed** event to the **Elevator**. The **Elevator** gets ready to leave by calling its **private** method **setMoving**, which changes the **Elevator**'s **boolean** attribute **moving** to **true**. The **Elevator** then closes the **elevatorDoor**, which closes the **Door** on that **Floor**. The **Person** then rides the **Elevator** by invoking the **Elevator**'s **synchronized** method **ride**. As in the collaboration diagram, the {concurrent} keyword placed after method **ride** indicates the method is **synchronized**, when implemented in Java.

The remainder of the diagram shows the sequence after the **Elevator**'s arrival at the destination **Floor** (also described in Fig. 15.9). Upon arrival, the **Elevator** stops moving by calling **private** method **setMoving**, which sets attribute **moving** to **false**. The **Elevator** then sends an **elevatorArrived** message to the **ElevatorDoor**, which opens the **Door** on that **Floor** and sends the **Person** a **doorOpened** message. Method **doorOpened** wakes the sleeping **Person**'s thread by invoking method **interrupt**, causing method **ride** to terminate and return the **Person**'s thread to the "ready" state. The **Person** exits the simulation shortly afterwards. Note the large "**X**" at the bottom of the **Person**'s lifeline. In a sequence diagram, this "**X**" indicates that the associated object destroys itself (in Java, the **Person** object is marked for garbage collection).

Our Final Class Diagram

The integration of multithreading in our elevator model concludes the design of the model. We implement this model in Appendix H. Figure 15.10 presents the complete class diagram we use when implementing the model. Note that the major difference between the class diagrams of Fig. 15.10 and Fig. 10.31 is the presence of active classes in Fig. 15.10. We have established that classes **Elevator** and **Person** are active classes. However, the problem statement mentioned that "if a person neither enters nor requests the elevator, the elevator closes its door." Having discussed multithreading, we believe that a better requirement would be for the **Door**s to close automatically (using a thread) if they have been open for more than a brief period (e.g., three seconds). In addition, although not mentioned in the problem statement, the **Light**s should turn off automatically—currently, the **Light**s turn off only when the **Elevator** departs from a **Floor**. We mark the **Door**s and **Light**s as active classes to handle this change. We implement this change in Appendix H.

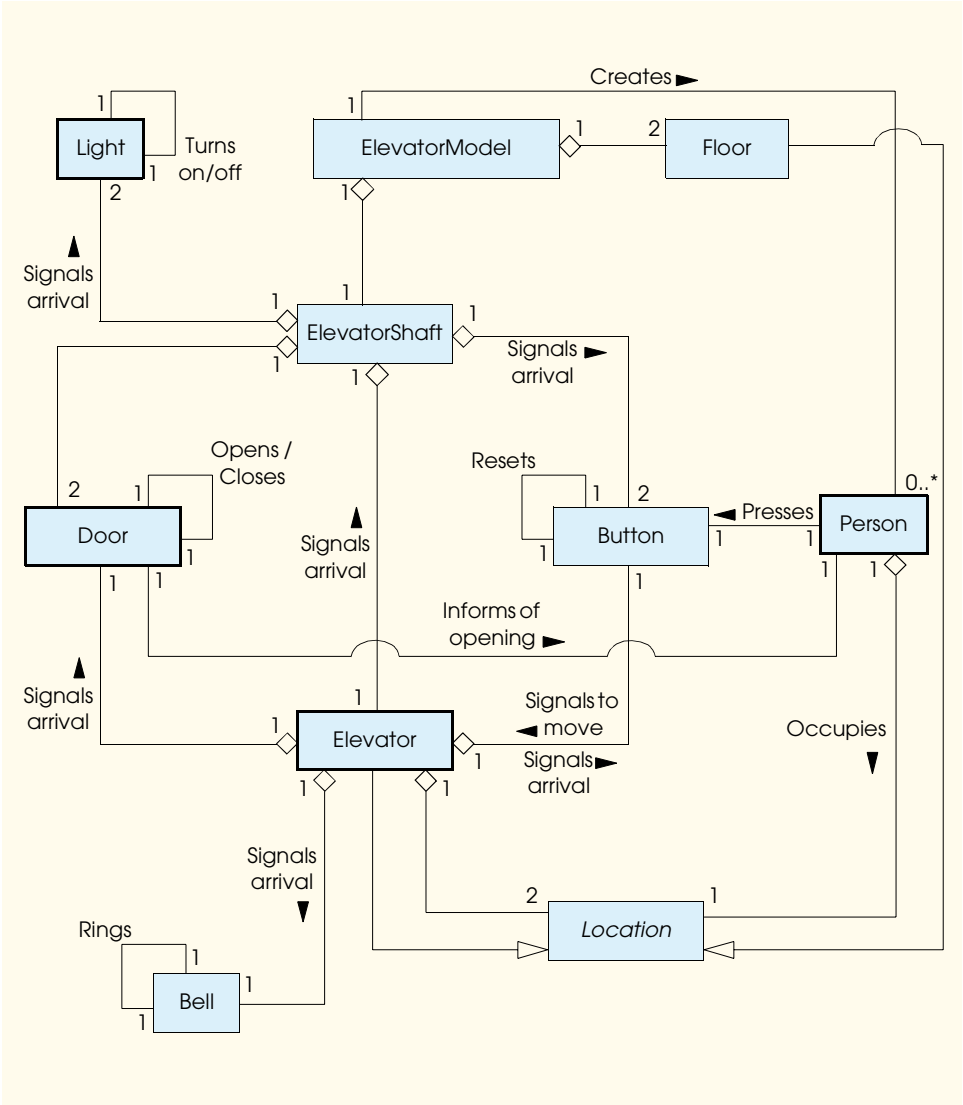


Fig. 15.10 Final class diagram of the elevator simulation

Figure 15.11 presents the attributes and operations for all classes in Fig. 15.10. We use both diagrams to implement the model. We have omitted method **`enterElevator`** and **`exitElevator`** from class **`Elevator`**, because as discussed in the interaction diagrams, method **`ride`** appears to handle the **`Person`**'s entering, riding and exiting the **`Elevator`**. In addition, we have replaced method **`departElevator`** with **`private`** method **`setMoving`**, because according to Fig. 15.9, method **`setMoving`** provides the service that allows the **`Elevator`** to depart from a **`Floor`**. We also include **`private`** attribute **`maxTravelTime`**, which represents the maximum time the **`Person`** will wait

to ride the **`Elevator`**, to class **`Person`**. We assign **`maxTravelTime`** a value of **`10`** minutes (**`10`** * **`60`** seconds). We will use these class diagrams to implement our Java code in Appendix H, but we will continue making subtle "Java-specific" adjustments to code. In the appendices, for each class, we create methods that access object references and implement interface methods.

In "Thinking About Objects" Section 22.9, we design the view—the display of our model. When we implement this display in Appendix I, we will have a fully functional 3,594-line elevator simulation.

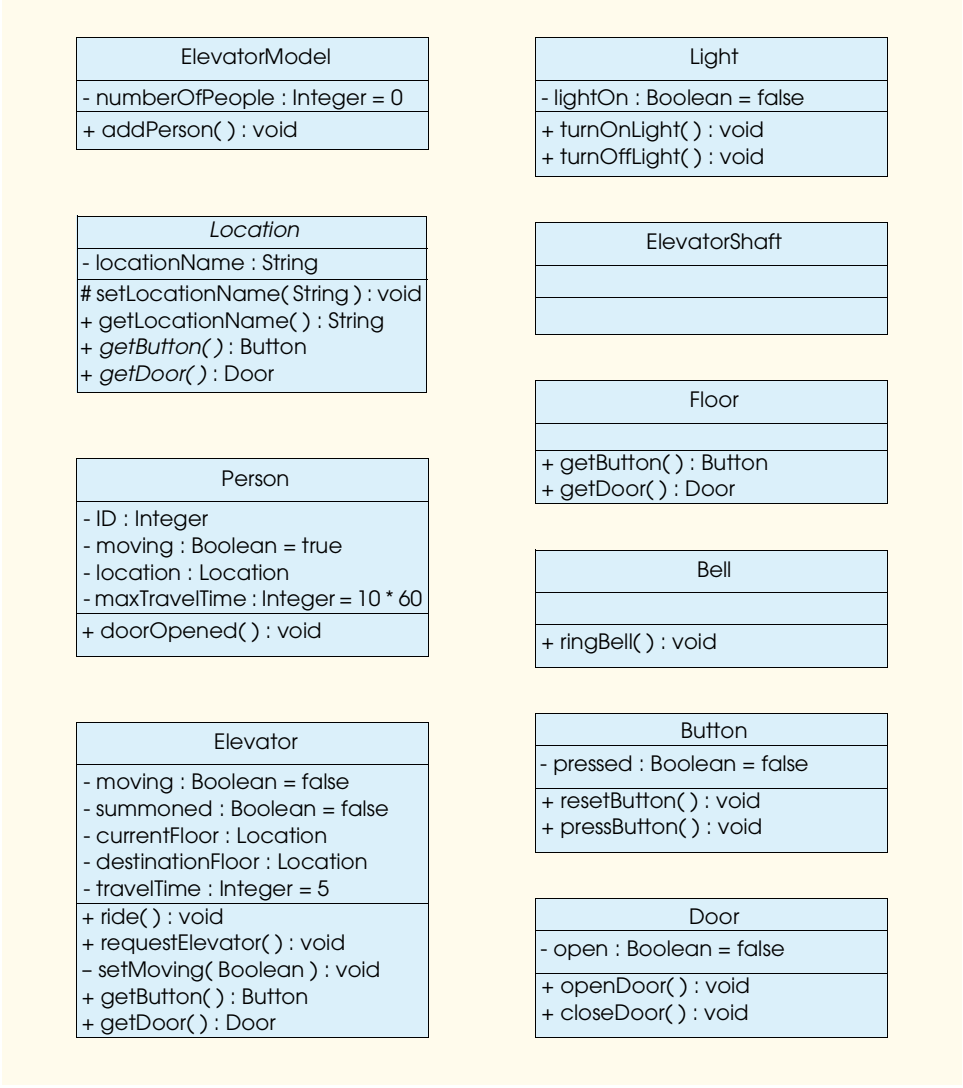


Fig. 15.11 Final class diagram with attributes and operations.

15.13 (Optional) Discovering Design Patterns: Concurrent Design Patterns

Many additional design patterns have been created since the publication of the gang-of-four book, which introduced patterns involving object-oriented systems. Some of these new patterns involve specific object-oriented systems, such as concurrent, distributed or parallel systems. In this section, we discuss concurrency patterns to conclude our discussion of multithreaded programming.

Concurrency Design Patterns

Multithreaded programming languages such as Java allow designers to specify concurrent activities—that is, those that operate in parallel with one another. Designing concurrent systems improperly can introduce concurrency problems. For example, two objects attempting to alter shared data at the same time could corrupt that data. In addition, if two objects wait for one another to finish tasks, and if neither can complete their task, these objects could potentially wait forever—a situation called *deadlock*. Using Java, Doug Lea[1] and Mark Grand[2] created *concurrency patterns* for multithreaded design architectures to prevent various problems associated with multithreading. We provide a partial list of these design patterns:

- The *Single-Threaded Execution design pattern* (Grand, 98) prevents several threads from invoking the same method of another object concurrently. In Java, the **`synchronized`** keyword (discussed in Chapter 15) can be used to apply this pattern.
- The *Guarded Suspension design pattern* (Lea, 97) suspends a thread's activity and resumes that thread's activity when some condition is satisfied. Lines 137–147 and lines 95–109 of class **`RandomCharacters`** (Fig. 15.17) use this design pattern—methods **`wait`** and **`notify`** suspend and resume, respectively, the program threads, and line 98 toggles the variable that the condition evaluates.
- The *Balking design pattern* (Lea, 97) ensures that a method will *balk*—that is, return without performing any actions—if an object occupies a state that cannot execute that method. A variation of this pattern is that the method throws an exception describing why that method is unable to execute—for example, a method throwing an exception when accessing a data structure that does not exist.
- The *Read/Write Lock design pattern* (Lea, 97) allows multiple threads to obtain concurrent read access on an object but prevents multiple threads from obtaining concurrent write access on that object. Only one thread at a time may obtain write access on an object—when that thread obtains write access, the object is *locked* to all other threads.
- The *Two-Phase Termination design pattern* (Grand, 98) uses a two-phase termination process for a thread to ensure that a thread frees resources—such as other spawned threads—in memory (phase one) before termination (phase two). In

1. D. Lea, *Concurrent Programing in Java, Second Edition: Design Principles and Patterns*. Massachusetts: Addison-Wesley. November 1999.
2. M. Grand, *Patterns in Java; A Catalog of Reusable Design Patterns Illustrated with UML*. New York: John Wiley and Sons, 1998.

Java, a **Thread** object can use this pattern in method **run**. For instance, method **run** can contain an infinite loop that is terminated by some state change—upon termination, method **run** can invoke a **private** method responsible for stopping any other spawned threads (phase one). The thread then terminates after method **run** terminates (phase two).

In "Discovering Design Patterns" Section 17.10, we return to the gang-of-four design patterns. Using the material introduced in Chapters 16 and 17, we identify those classes in package **java.io** and **java.net** that use design patterns.

SUMMARY

- Computers perform operations concurrently, such as compiling a program, printing a file and receiving e-mail messages over a network.
- Programming languages generally provide only a simple set of control structures that enable programmers to perform one action at a time, then proceed to the next action after the previous one is finished.
- The concurrency that computers perform today is normally implemented as operating system "primitives" available only to highly experienced "systems programmers."
- Java makes concurrency primitives available to the programmer.
- Applications contain threads of execution, each thread designating a portion of a program that may execute concurrently with other threads. This capability is called multithreading.
- Java provides a low-priority garbage collector thread that reclaims dynamically allocated memory that is no longer needed. The garbage collector runs when processor time is available and there are no higher priority runnable threads. The garbage collector runs immediately when the system is out of memory to try to reclaim memory.
- Method **run** contains the code that controls a thread's execution.
- A program launches a thread's execution by calling the thread's **start** method, which, in turn, calls method **run**.
- Method **interrupt** is called to interrupt a thread.
- Method **isAlive** returns **true** if **start** has been called for a given thread and the thread is not dead (i.e., the **run** method has not completed execution).
- Method **setName** sets the name of the **Thread**. Method **getName** returns the name of the **Thread**. Method **toString** returns a **String** consisting of the name of the thread, the priority of the thread and the thread's group.
- **Thread static** method **currentThread** returns a reference to the executing **Thread**.
- Method **join** waits for the **Thread** on which **join** is called to die before the current **Thread** can proceed.
- Waiting can be dangerous; it can lead to two serious problems called deadlock and indefinite postponement. Indefinite postponement is also called starvation.
- A thread that was just created is in the born state. The thread remains in this state until the thread's **start** method is called; this causes the thread to enter the ready state.
- A highest priority-ready thread enters the *running state* when the system assigns a processor to the thread.
- A thread enters the dead state when its **run** method completes or terminates for any reason. The system eventually will dispose of a dead thread.

- A *running* thread enters the blocked state when the thread issues an input/output request. A blocked thread becomes ready when the I/O it is waiting for completes. A blocked thread cannot use a processor even if one is available.
- When a running method calls **`wait`**, the thread enters a waiting state for the particular object in which the thread was running. A thread in the waiting state for a particular object becomes ready on a call to **`notify`** issued by another thread associated with that object.
- Every thread in the waiting state for a given object becomes ready on a call to **`notifyAll`** by another thread associated with that object.
- Every Java thread has a priority in the range **`Thread.MIN_PRIORITY`** (a constant of 1) and **`Thread.MAX_PRIORITY`** (a constant of 10). By default, each thread is given priority **`Thread.NORM_PRIORITY`** (a constant of 5).
- Some Java platforms support a concept called timeslicing and some do not. Without timeslicing, threads of equal priority run to completion before their peers get a chance to execute. With timeslicing, each thread receives a brief burst of processor time called a quantum during which that thread can execute. At the completion of the quantum, even if that thread has not finished executing, the processor is taken away from that thread and given to the next thread of equal priority, if one is available.
- The job of the Java scheduler is to keep a highest priority thread running at all times and, if timeslicing is available, to ensure that several equally high-priority threads each execute for a quantum in round-robin fashion.
- A thread's priority can be adjusted with the **`setPriority`** method. Method **`getPriority`** returns the thread's priority.
- A thread can call the **`yield`** method to give other threads a chance to execute.
- Every object that has **`synchronized`** methods has a monitor. The monitor lets only one thread at a time execute a **`synchronized`** method on the object.
- A thread executing in a **`synchronized`** method may determine that it cannot proceed, so the thread voluntarily calls **`wait`**. This removes the thread from contention for the processor and from contention for the object.
- A thread that has called **`wait`** is awakened by a thread that calls **`notify`**. The **`notify`** acts as a signal to the waiting thread that the condition the waiting thread has been waiting for is now (or could be) satisfied, so it is acceptable for that thread to reenter the monitor.
- A daemon thread serves other threads. When only daemon threads remain in a program, Java will exit. If a thread is to be a daemon, it must be set as such before its **`start`** method is called.
- To support multithreading in a class derived from some class other than **`Thread`**, implement the **`Runnable`** interface in that class.
- Implementing the **`Runnable`** interface gives us the ability to treat the new class as a **`Runnable`** object (just like inheriting from a class allows us to treat our subclass as an object of its superclass). As with deriving from the **`Thread`** class, the code that controls the thread is placed in the **`run`** method.
- A thread with a **`Runnable`** class is created by passing to the **`Thread`** class constructor a reference to an object of the class that implements the **`Runnable`** interface. The **`Thread`** constructor registers the **`run`** method of the **`Runnable`** object as the method to be invoked when the thread begins execution.
- Class **`ThreadGroup`** contains the methods for creating and manipulating groups of related threads in a program.

TERMINOLOGY

asynchronous threads
blocked (state of a thread)
blocked on I/O
busy wait
child thread group
circular buffer
concurrent execution of threads
condition variable
consumer
consumer thread
context
`currentThread` method
daemon thread
dead (state of a thread)
deadlock
`destroy` method
`dumpStack` method
`Error` class **`ThreadDeath`**
execution context
fixed-priority scheduling
garbage collection by a low-priority thread
`getName` method
`getParent` method of **`ThreadGroup`** class
highest priority runnable thread
I/O completion
`IllegalArgumentException`
`IllegalMonitorStateException`
`IllegalThreadStateException`
indefinite postponement
inherit thread priority
`interrupt` method
`interrupted` method
`InterruptedException`
`InterruptedException` class
interthread communication
`isAlive` method
`isDaemon` method
`isInterrupted` method
`join` method
kill a thread
`MAX_PRIORITY`(10)
memory leak
`MIN_PRIORITY`(1)
monitor
multiple inheritance
multiprocessing
multithreaded program
multithreaded server
multithreading
new (state of a thread)
nonpreemptive scheduling
`NORM_PRIORITY`(5)
`notify` method
`notifyAll` method
parallelism
parent thread
parent thread group
preemptive scheduling
priority of a thread
producer thread
producer/consumer relationship
programmer-defined thread
quantum
round-robin scheduling
`run` method
`Runnable` interface (in **`java.lang`** package)
runnable state (of a thread)
running (thread state)
scheduler
scheduling a thread
`setDaemon` method
`setName` method
`setPriority` method
shared objects
single-threaded language
single-threaded program
`sleep` method of **`Thread`** class
sleeping state (of a thread)
`start` method
starvation
synchronization
`synchronized` method
thread
`Thread` class (in **`java.lang`** package)
thread group
thread priority
thread safe
thread states
thread synchronization
`Thread.MAX_PRIORITY`
`Thread.MIN_PRIORITY`
`Thread.NORM_PRIORITY`
`Thread.sleep()`
`ThreadDeath` exception
`ThreadGroup` class
timeslicing
`wait` method
`yield` method

SELF-REVIEW EXERCISES

15.1 Fill in the blanks in each of the following statements:

a) C and C++ are _____-threaded languages whereas Java is a _____-threaded language.
b) Java provides a _____ thread that reclaims dynamically allocated memory.
c) Java eliminates most _____ errors that occur commonly in languages like C and C++ when dynamically allocated memory is not explicitly reclaimed by the program.
d) Three reasons a thread that is alive could be not runnable (i.e., blocked) are _____, _____ and _____.
e) A thread enters the dead state when _____.
f) A thread's priority can be changed with the _____ method.
g) A thread may give up the processor to a thread of the same priority by calling the method.
h) To wait for a designated number of milliseconds and resume execution, a thread should call the _____ method.
i) The _____ method moves a thread in the object's *waiting* state to the ready state.

15.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) A thread is not runnable if it is dead.
b) In Java, a higher priority runnable thread will preempt threads of lower priority.
c) The Windows and Windows NT Java systems use timeslicing. Therefore, they can enable threads to preempt threads of the same priority.
d) Threads may **`yield`** to threads of lower priority.

ANSWERS TO SELF-REVIEW EXERCISES

15.1 a) single, multi. b) garbage collector. c) memory leak. d) waiting, sleeping, blocked for input/output. e) its **`run`** method terminates. f) **`setPriority`**. g) **`yield`**. h) **`sleep`**. i) **`notify`**.

15.2 a) True. b) True. c) False. Timeslicing allows a thread to execute until its timeslice (or quantum) expires. Then other threads of equal priority can execute. d) False. Threads can only yield to threads of equal priority.

EXERCISES

15.3 State whether each of the following is *true* or *false*. If *false*, explain why.

a) The **`sleep`** method does not consume processor time while a thread sleeps.
b) Declaring a method **`synchronized`** guarantees that deadlock cannot occur.
c) Java provides a powerful capability called multiple inheritance.
d) **`Thread`** methods **`suspend`** and **`resume`** are deprecated.

15.4 Define each of the following terms.

a) thread
b) multithreading
c) ready state
d) blocked state
e) preemptive scheduling
f) **`Runnable`** interface
g) monitor
h) **`notify`** method
i) producer/consumer relationship

15.5 a) List each of the reasons stated in this chapter for using multithreading.
b) List additional reasons for using multithreading.

15.6 List each of the three reasons given in the text for entering the blocked state. For each of these, describe how the program will normally leave the blocked state and enter the runnable state.

15.7 Distinguish between preemptive scheduling and nonpreemptive scheduling. Which does Java use?

15.8 What is timeslicing? Give a fundamental difference in how scheduling is performed on Java systems that support timeslicing vs. scheduling on Java systems that do not support timeslicing.

15.9 Why would a thread ever want to call **`yield`**?

15.10 What aspects of developing Java applets for the World Wide Web encourage applet designers to use **`yield`** and **`sleep`** abundantly?

15.11 If you choose to write your own **`start`** method, what must you be sure to do to ensure that your threads start up properly?

15.12 Distinguish among each of the following means of pausing threads:
a) busy wait
b) sleep
c) blocking I/O

15.13 Write a Java statement that tests if a thread is alive.

15.14 a) What is multiple inheritance?
b) Explain why Java does not offer multiple inheritance.
c) What feature does Java offer instead of multiple inheritance?
d) Explain the typical use of this feature.
e) How does this feature differ from **`abstract`** classes?

15.15 Distinguish between the notions of **`extends`** and **`implements`**.

15.16 Discuss each of the following terms in the context of monitors:
a) monitor
b) producer
c) consumer
d) **`wait`**
e) **`notify`**
f) **`InterruptedException`**
g) **`synchronized`**

15.17 (Tortoise and the Hare) In the Chapter 7 exercises, you were asked to simulate the legendary race of the tortoise and the hare. Implement a new version of that simulation, this time placing each of the animals in a separate thread. At the start of the race call the **`start`** methods for each of the threads. Use **`wait`**, **`notify`** and **`notifyAll`** to synchronize the animals' activities.

15.18 (Multithreaded, Networked, Collaborative Applications) In Chapter 17, we cover networking in Java. A multithreaded Java application can communicate concurrently with several host computers. This creates the possibility of being able to build some interesting kinds of collaborative applications. In anticipation of studying networking in Chapter 17, develop proposals for several possible multithreaded networked applications. After studying Chapter 17, implement some of those applications.

15.19 Write a Java program to demonstrate that as a high-priority thread executes, it will delay the execution of all lower priority threads.

15.20 If your system supports timeslicing, write a Java program that demonstrates timeslicing among several equal-priority threads. Show that a lower priority thread's execution is deferred by the timeslicing of the higher-priority threads.

15.21 Write a Java program that demonstrates a high priority thread using **`sleep`** to give lower priority threads a chance to run.

15.22 If your system does not support timeslicing, write a Java program that demonstrates two threads using **`yield`** to enable one another to execute.

15.23 Two problems that can occur in systems like Java, that allow threads to wait, are deadlock, in which one or more threads will wait forever for an event that cannot occur, and indefinite postponement, in which one or more threads will be delayed for some unpredictably long time. Give an example of how each of these problems can occur in a multithreaded Java program.

15.24 (Readers and Writers) This exercise asks you to develop a Java monitor to solve a famous problem in concurrency control. This problem was first discussed and solved by P. J. Courtois, F. Heymans and D. L. Parnas in their research paper, "Concurrent Control with Readers and Writers," *Communications of the ACM*, Vol. 14, No. 10, October 1971, pp. 667–668. The interested student might also want to read C. A. R. Hoare's seminal research paper on monitors, "Monitors: An Operating System Structuring Concept," *Communications of the ACM*, Vol. 17, No. 10, October 1974, pp. 549–557. Corrigendum, *Communications of the ACM*, Vol. 18, No. 2, February 1975, p. 95. [The readers and writers problem is discussed at length in Chapter 5 of the author's book: Deitel, H. M., *Operating Systems*, Reading, MA: Addison-Wesley, 1990.]

a) With multithreading, many threads can access shared data; as we have seen, access to shared data needs to be synchronized carefully to avoid corrupting the data.

b) Consider an airline-reservation system in which many clients are attempting to book seats on particular flights between particular cities. All of the information about flights and seats is stored in a common database in memory. The database consists of many entries, each representing a seat on a particular flight for a particular day between particular cities. In a typical airline-reservation scenario, the client will probe around in the database looking for the "optimal" flight to meet that client's needs. So a client may probe the database many times before deciding to book a particular flight. A seat that was available during this probing phase could easily be booked by someone else before the client has a chance to book it. In that case, when the client attempts to make the reservation, the client will discover that the data has changed and the flight is no longer available.

c) The client probing around the database is called a reader. The client attempting to book the flight is called a writer. Clearly, any number of readers can be probing shared data at once, but each writer needs exclusive access to the shared data to prevent the data from being corrupted.

d) Write a multithreaded Java program that launches multiple reader threads and multiple writer threads, each attempting to access a single reservation record. A writer thread has two possible transactions, **`makeReservation`** and **`cancelReservation`**. A reader has one possible transaction, **`queryReservation`**.

e) First implement a version of your program that allows unsynchronized access to the reservation record. Show how the integrity of the database can be corrupted. Next implement a version of your program that uses Java monitor synchronization with **`wait`** and **`notify`** to enforce a disciplined protocol for readers and writers accessing the shared reservation data. In particular, your program should allow multiple readers to access the shared data simultaneously when no writer is active. But if a writer is active, then no readers should be allowed to access the shared data.

f) Be careful. This problem has many subtleties. For example, what happens when there are several active readers and a writer wants to write? If we allow a steady stream of readers to arrive and share the data, they could indefinitely postpone the writer (who may become tired of waiting and take his or her business elsewhere). To solve this problem, you might decide to favor writers over readers. But here, too, there is a trap, because a steady stream of writers could then indefinitely postpone the waiting readers, and they, too, might choose to take their business elsewhere! Implement your monitor with the following methods: **`startReading`**, which is called by any reader who wants to begin accessing

a reservation; **`stopReading`** to be called by any reader who has finished reading a reservation; **`startWriting`** to be called by any writer who wants to make a reservation and **`stopWriting`** to be called by any writer who has finished making a reservation.

15.25 Write a program that bounces a blue ball inside an applet. The ball should be initiated with a **`mousePressed`** event. When the ball hits the edge of the applet, the ball should bounce off the edge and continue in the opposite direction.

15.26 Modify the program of Exercise 15.25 to add a new ball each time the user clicks the mouse. Provide for a minimum of 20 balls. Randomly choose the color for each new ball.

15.27 Modify the program of Exercise 15.26 to add shadows. As a ball moves, draw a solid black oval at the bottom of the applet. You may consider adding a 3-D effect by increasing or decreasing the size of each ball when a ball hits the edge of the applet.

15.28 Modify the program of Exercise 15.25 or 15.26 to bounce the balls off each other when they collide.

16

Files and Streams

Objectives

- To be able to create, read, write and update files.
- To understand the Java streams class hierarchy.
- To be able to use the **`FileInputStream`** and **`FileOutputStream`** classes.
- To be able to use the **`ObjectInputStream`** and **`ObjectOutputStream`** classes.
- To be able to use class **`RandomAccessFile`**.
- To be able to use a **`JFileChooser`** dialog to access files and directories.
- To become familiar with sequential-access and random-access file processing.
- To be able to use class **`File`**.

I can only assume that a "Do Not File" document is filed in a "Do Not File" file.
Senator Frank Church
Senate Intelligence Subcommittee Hearing, 1975

Consciousness … does not appear to itself chopped up in bits. … A "river" or a "stream" are the metaphors by which it is most naturally described.
William James

I read part of it all the way through.
Samuel Goldwyn

It is quite a three-pipe problem.
Sir Arthur Conan Doyle

Outline

16.1 Introduction
16.2 Data Hierarchy
16.3 Files and Streams
16.4 Creating a Sequential-Access File
16.5 Reading Data from a Sequential-Access File
16.6 Updating Sequential-Access Files
16.7 Random-Access Files
16.8 Creating a Random-Access File
16.9 Writing Data Randomly to a Random-Access File
16.10 Reading Data Sequentially from a Random-Access File
16.11 Example: A Transaction-Processing Program
16.12 Class `File`

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

16.1 Introduction

Storage of data in variables and arrays is temporary—the data is lost when a local variable "goes out of scope" or when the program terminates. Programs use *files* for long-term retention of large amounts of data, even after programs that create the data terminate. We refer to data maintained in files as *persistent data*, because the data exists beyond the duration of program execution. Computers store files on *secondary storage devices* such as magnetic disks, optical disks and magnetic tapes. In this chapter, we explain how Java programs create, update and process data files. We consider both "sequential-access" files and "random-access" files and discuss typical applications for each.

File processing is one of the most important capabilities a language must have to support commercial applications that typically process massive amounts of persistent data. In this chapter, we discuss Java's powerful file-processing and stream input/output features. File processing is a subset of Java's stream-processing capabilities that enable a program to read and write bytes in memory, in files and over network connections. We have two goals in this chapter—to introduce file-processing paradigms and to provide the reader with sufficient stream-processing capabilities to support the networking features introduced in Chapter 17.

Software Engineering Observation 16.1

It would be dangerous to enable applets arriving from anywhere on the World Wide Web to be able to read and write files on the client system. By default, Web browsers prevent applets from performing file processing on the client system. Therefore, file-processing programs generally are implemented as Java applications.

16.2 Data Hierarchy

Ultimately, a computer processes all data items as combinations of zeros and ones, because it is simple and economical for engineers to build electronic devices that can assume two stable states—one state represents `0`, the other state represents `1`. It is remarkable that the

impressive functions performed by computers involve only the most fundamental manipulations of **0**s and **1**s.

The smallest data item in a computer can assume the value **0** or the value **1**. Such a data item is called a *bit* (short for "*b*inary dig*it*"—a digit that can assume one of two values). Computer circuitry performs various simple bit manipulations, such as examining the value of a bit, setting the value of a bit and reversing a bit (from **1** to **0** or from **0** to **1**).

It is cumbersome for programmers to work with data in the low-level form of bits. Instead, programmers prefer to work with data in such forms as *decimal digits* (0–9), *letters* (A–Z and a–z), and *special symbols* (e.g., $, @, %, &, *, (,), -, +, ", :, ?, / and many others). Digits, letters and special symbols are known as *characters.* The computer's *character set* is the set of all characters used to write programs and represent data items. Computers can process only **1**s and **0**s, so a computer's character set represents every character as a pattern of **1**s and **0**s. Characters in Java are *Unicode* characters composed of 2 *bytes*. Bytes are most commonly composed of eight bits. Programmers create programs and data items with characters. Computers manipulate and process these characters as patterns of bits. See Appendix K for more information on Unicode.

Just as characters are composed of bits, *fields* are composed of characters or bytes. A field is a group of characters or bytes that conveys meaning. For example, a field consisting of uppercase and lowercase letters can be used to represent a person's name.

Data items processed by computers form a *data hierarchy* in which data items become larger and more complex in structure as we progress from bits, to characters, to fields, etc.

Typically, several fields (called instance variables in Java) compose a *record* (implemented as a **class** in Java). In a payroll system, for example, a record for a particular employee might consist of the following fields (possible data types for these fields are shown in parentheses following each field):

- Employee identification number (**int**)
- Name (**String**)
- Address (**String**)
- Hourly pay rate (**double**)
- Number of exemptions claimed (**int**)
- Year-to-date earnings (**int** or **double**)
- Amount of taxes withheld (**int** or **double**)

Thus, a record is a group of related fields. In the preceding example, each of the fields belongs to the same employee. Of course, a particular company might have many employees and will have a payroll record for each employee. A *file* is a group of related records.[1] A company's payroll file normally contains one record for each employee. Thus, a payroll file for a small company might contain only 22 records, whereas a payroll file for a large company might contain 100,000 records. It is not unusual for a company to have many files, some containing millions, or even billions, of characters of information. Figure 16.1 illustrates the *data hierarchy*.

1. More generally, a file can contain arbitrary data in arbitrary formats. In some operating systems, a file is viewed as nothing more than a collection of bytes. In such an operating system, any organization of the bytes in a file (such as organizing the data into records) is a view created by the applications programmer.

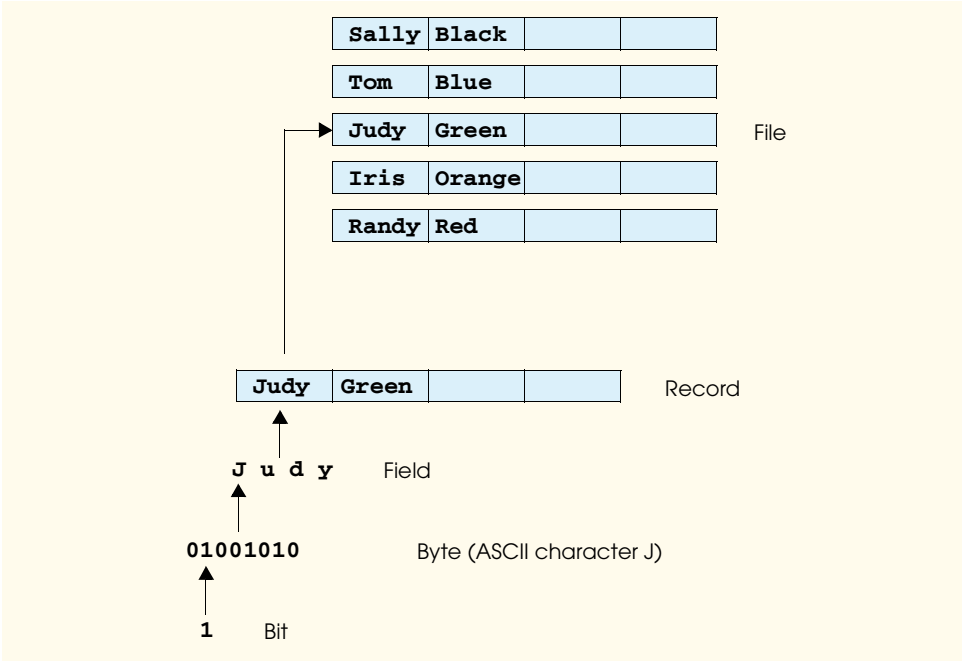


Fig. 16.1 The data hierarchy.

To facilitate the retrieval of specific records from a file, at least one field in each record is chosen as a *record key*. A record key identifies a record as belonging to a particular person or entity that is unique from all other records. In the payroll record described previously, the employee identification number normally would be chosen as the record key.

There are many ways to organize records in a file. The most common organization is called a *sequential file* in which records are stored in order by the record-key field. In a payroll file, records are placed in order by employee identification number. The first employee record in the file contains the lowest employee identification number, and subsequent records contain increasingly higher employee identification numbers.

Most businesses store data in many different files. For example, companies might have payroll files, accounts receivable files (listing money due from clients), accounts payable files (listing money due to suppliers), inventory files (listing facts about all the items handled by the business) and many other file types. Often, a group of related files is called a *database*. A collection of programs designed to create and manage databases is called a *database management system* (DBMS).

16.3 Files and Streams

Java views each file as a sequential *stream* of bytes (Fig. 16.2). Each file ends either with an *end-of-file marker* or at a specific byte number recorded in a system-maintained administrative data structure. Java abstracts this concept from the programmer. A Java program processing a stream of bytes simply receives an indication from the system when the program reaches the end of the stream—the program does not need to know how the underly-

ing platform represents files or streams. In some cases, the end-of-file indication occurs as an exception. In other cases, the indication is a return value from a method invoked on a stream-processing object. We demonstrate both cases in this chapter.

A Java program *opens* a file by creating an object and associating a stream of bytes with the object. Java also can associates streams of bytes associated with devices. In fact, Java creates three stream objects that are associated with devices when a Java program begins executing—***System.in***, ***System.out*** and ***System.err***. The streams associated with these objects provide communication channels between a program and a particular device. For example, object **System.in** (the *standard input stream object*) normally enables a program to input bytes from the keyboard, object **System.out** (the *standard output stream object*) normally enables a program to output data to the screen and object **System.err** (the *standard error stream object*) normally enables a program to output error messages to the screen. Each of these streams can be *redirected*. For **System.in**, this enables the program to read bytes from a different source. For **System.out** and **System.err**, this enables the output to be sent to a different location, such as a file on disk. Class **System** provides methods ***setIn***, ***setOut*** and ***setErr*** to redirect the standard input, output and error streams.

Java programs perform file processing by using classes from package ***java.io***. This package includes definitions for the stream classes, such as ***FileInputStream*** (for byte-based input from a file), ***FileOutputStream*** (for byte-based output to a file), ***FileReader*** (for character-based input from a file) and ***FileWriter*** (for character-based output to a file). Files are opened by creating objects of these stream classes that inherit from classes **InputStream**, **OutputStream**, **Reader** and **Writer**, respectively. Thus, the methods of these stream classes can all be applied to file streams as well. To perform input and output of data types, objects of class **ObjectInputStream**, **DataInputStream**, **ObjectOutputStream** and **DataOutputStream** will be used together with the byte-based file stream classes **FileInputStream** and **FileOutputStream**. Figure 16.3 summarizes the inheritance relationships of many of the Java I/O classes (**abstract** classes are shown in italic font). The following discussion overviews the capabilities of each of the classes in Fig. 16.3.

Java offers many classes for performing input/output. This section briefly overviews many of these classes and explains how they relate to one another. In the rest of the chapter, we use several of these stream classes as we implement a variety of file-processing programs that create, manipulate and destroy sequential-access files and random-access files. We also include a detailed example on class **File**, which is useful for obtaining information about files and directories. In Chapter 17, Networking, we use stream classes extensively to implement networking applications.

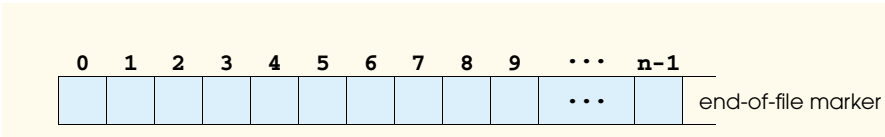


Fig. 16.2 Java's view of a file of *n* bytes.

A portion of the class hierarchy of the `java.io` package

```
java.lang.Object
   File
   FileDescriptor
   InputStream
      ByteArrayInputStream
      FileInputStream
      FilterInputStream
         BufferedInputStream
         DataInputStream
         PushbackInputStream
      ObjectInputStream
      PipedInputStream
      SequenceInputStream
   OutputStream
      ByteArrayOutputStream
      FileOutputStream
      FilterOutputStream
         BufferedOutputStream
         DataOutputStream
         PrintStream
      ObjectOutputStream
      PipedOutputStream
   RandomAccessFile
   Reader
      BufferedReader
         LineNumberReader
      CharArrayReader
      FilterReader
         PushbackReader
      InputStreamReader
         FileReader
      PipedReader
      StringReader
```

Fig. 16.3 A portion of the class hierarchy of the **`java.io`** package (part 1 of 2).

A portion of the class hierarchy of the `java.io` package

```
Writer
   BufferedWriter
   CharArrayWriter
   FilterWriter
   OutputStreamWriter
      FileWriter
   PipedWriter
   PrintWriter
   StringWriter
```

Fig. 16.3 A portion of the class hierarchy of the **`java.io`** package (part 2 of 2).

InputStream and ***OutputStream*** (subclasses of **`Object`**) are **`abstract`** classes that define methods for performing byte-based input and output, respectively.

Programs perform byte-based file input/output with ***FileInputStream*** (a subclass of **`InputStream`**) and ***FileOutputStream*** (a subclass of **`OutputStream`**). We use these classes extensively in the examples in this chapter.

Pipes are synchronized communication channels between threads or processes. Java provides ***PipedOutputStream*** (a subclass of **`OutputStream`**) and ***PipedInputStream*** (a subclass of **`InputStream`**) to establish pipes between two threads. One thread sends data to another by writing to a **`PipedOutputStream`**. The target thread reads information from the pipe via a **`PipedInputStream`**.

A ***PrintStream*** (a subclass of **`FilterOutputStream`**) performs text output to the specified stream. Actually, we have been using **`PrintStream`** output throughout the text to this point—**`System.out`** is a **`PrintStream`**, as is **`System.err`**.

A **`FilterInputStream`** *filters* an **`InputStream`**, and a **`FilterOutStream`** filters an **`OutputStream`**; filtering simply means that the filter stream provides additional functionality, such as buffering, monitoring line numbers or aggregating data bytes into meaningful primitive-data-type units. **`FilterInputStream`** and **`FilterOutputStream`** are **`abstract`** classes, so additional functionality is provided by their subclasses.

Reading data as raw bytes is fast but crude. Usually programs read data as aggregates of bytes that form an **`int`**, a **`float`**, a **`double`** and so on. Java programs can use several classes to input and output data in aggregate form.

A ***RandomAccessFile*** is useful for direct-access applications, such as transaction-processing applications like airline-reservations systems and point-of-sale systems. With a sequential-access file, each successive input/output request reads or writes the next consecutive set of data in the file. With a random-access file, each successive input/output request could be directed to any part of the file—perhaps one widely separated from the part of the file referenced in the previous request. Direct-access applications provide rapid access to specific data items in large files; often, such applications are used in applications that require users to wait for answers—these answers must be made available quickly, or the people might become impatient and "take their business elsewhere."

The **DataInput** interface is implemented by class **DataInputStream** and class **RandomAccessFile** (discussed later in the chapter); each needs to read primitive data types from a stream. **DataInputStream**s enable a program to read binary data from an **InputStream**. The **DataInput** interface includes methods **read** (for **byte** arrays), **readBoolean**, **readByte**, **readChar**, **readDouble**, **readFloat**, **readFully** (for **byte** arrays), **readInt**, **readLong**, **readShort**, **readUnsignedByte**, **readUnsignedShort**, **readUTF** (for strings) and **skipBytes**.

The **DataOutput** interface is implemented by class **DataOutputStream** (a subclass of **FilterOutputStream**) and class **RandomAccessFile**; each needs to write primitive data types to an **OutputStream**. **DataOutputStream**s enable a program to write binary data to an **OutputStream**. The **DataOutput** interface includes methods **flush**, **size**, **write** (for a **byte**), **write** (for a **byte** array), **writeBoolean**, **writeByte**, **writeBytes**, **writeChar**, **writeChars** (for Unicode **String**s), **writeDouble**, **writeFloat**, **writeInt**, **writeLong**, **writeShort** and **writeUTF**.

Buffering is an I/O-performance-enhancement technique. With a ***BufferedOutputStream*** (a subclass of class **FilterOutputStream**), each output statement does not necessarily result in an actual physical transfer of data to the output device. Rather, each output operation is directed to a region in memory called a buffer that is large enough to hold the data of many output operations. Then, actual transfer to the output device is performed in one large *physical output operation* each time the buffer fills. The output operations directed to the output buffer in memory are often called *logical output operations*. With a **BufferedOutputStream**, a partially filled buffer can be forced out to the device at any time by invoking the stream object's **flush** method.

Performance Tip 16.1

Since typical physical output operations are extremely slow compared to the speed of accessing computer memory, buffered outputs normally yield significant performance improvements over unbuffered outputs.

With a ***BufferedInputStream*** (a subclass of class **FilterInputStream**), many "logical" chunks of data from a file are read as one large *physical input operation* into a memory buffer. As a program requests each new chunk of data, it is taken from the buffer (this is sometimes referred to as a *logical input operation*). When the buffer is empty, the next actual physical input operation from the input device is performed to read in the next group of "logical" chunks of data. Thus, the number of actual physical input operations is small compared with the number of read requests issued by the program.

Performance Tip 16.2

Since typical input operations are extremely slow compared to the speed of accessing computer memory, buffered inputs normally yield significant performance improvements over unbuffered inputs.

A ***PushbackInputStream*** (a subclass of class **FilterInputStream**) is for applications more exotic than those most programmers require. Essentially, the application reading a **PushbackInputStream** reads bytes from the stream and forms aggregates consisting of several bytes. Sometimes, to determine that one aggregate is complete, the application must read the first character "past the end" of the first aggregate. Once the program determines that the current aggregate is complete, the extra character is "pushed

back" onto the stream. **PushbackInputStream**s are used by programs (like compilers) that parse their inputs—that is, break them into meaningful units (such as the keywords, identifiers and operators that the compiler must recognize).

When object instance variables are output to a disk file, in a sense we lose the object's type information. We have only data, not type information, on a disk. If the program that is going to read this data knows what object type it corresponds to, then the data is simply read into objects of that type. Sometimes, we would like to read or write an entire object to a file. The ***ObjectInputStream*** and ***ObjectOutputStream*** classes, which respectively implement the ***ObjectInput*** and ***ObjectOutput*** interfaces, enable an entire object to be read from or written to a file (or other stream type). We often chain **ObjectInputStream**s to **FileInputStream**s. (We also chain **ObjectOutputStream**s to **FileOutputStream**s.) The **ObjectOutput** interface contains method **writeObject**, which takes an **Object** that implements interface ***Serializable*** as an argument and writes its information to the **OutputStream**. Correspondingly, the **ObjectInput** interface requires method **readObject**, which reads and returns an **Object** from an **InputStream**. After the reading of an object, it can be cast to the desired type. Additionally, these interfaces include other **Object**-centric methods as well as the same methods as **DataInput** and **DataOutput** for reading and writing primitive data types.

Java stream I/O includes capabilities for inputting from **byte** arrays in memory and outputting to **byte** arrays in memory. A **ByteArrayInputStream** (a subclass of **InputStream**) reads from a **byte** array in memory. A **ByteArrayOutputStream** (a subclass of **OutputStream**) outputs to a **byte** array in memory. One application of **byte**-array I/O is data validation. A program can input an entire line at a time from the input stream into a **byte** array. Then, a validation routine can scrutinize the contents of the **byte** array and correct the data, if necessary. Then, the program can proceed to input from the **byte** array, knowing that the input data is in the proper format. Outputting to a **byte** array is a nice way to take advantage of the powerful output-formatting capabilities of Java streams. For example, data can be prepared in a **byte** array, using the same formatting that will be displayed at a later time, then output to a disk file to preserve the screen image.

A **SequenceInputStream** (a subclass of **InputStream**) enables concatenation of several **InputStream**s, so that the program sees the group as one continuous **InputStream**. As the program reaches the end of an input stream, that stream closes and the next stream in the sequence opens.

In addition to the byte based streams, Java provides ***Reader*** and ***Writer*** classes, which are Unicode, two-byte, character based streams. Most of the byte-based streams have corresponding character-based **Reader** or **Writer** classes.

Class ***BufferedReader*** (a subclass of **abstract** class **Reader**) and class ***BufferedWriter*** (a subclass of **abstract** class **Writer**) enable efficient buffering for character-based streams. Character-based streams use Unicode characters—such streams can process data in any language that the Unicode character set represents.

Class ***CharArrayReader*** and class ***CharArrayWriter*** read and write a stream of characters to a character array.

A ***PushbackReader*** (a subclass of **abstract** class ***FilterReader***) enables characters to be pushed back on a character stream. A ***LineNumberReader*** (a subclass of ***BufferedReader***) is a buffered character-stream that keeps track of line numbers (i.e., a newline, a return or a carriage-return line-feed combination).

Class **FileReader** (a subclass of **InputStreamReader**) and class **FileWriter** (a subclass of **OutputStreamWriter**) read characters from and write characters to a file, respectively. Class **PipedReader** and class **PipedWriter** implement piped-character streams that can be used to transfer information between threads. Class **StringReader** and **StringWriter** read and write characters to **String**s. A **PrintWriter** writes characters to a stream.

Class **File** enables programs to obtain information about a file or directory. We discuss class **File** extensively in Section 16.12.

16.4 Creating a Sequential-Access File

Java imposes no structure on a file. Notions like "record" do not exist in Java files. Therefore, the programmer must structure files to meet the requirements of applications. In the following example, we see how the programmer can impose a simple record structure on a file. First we present the program, then we analyze it in detail.

The program of Fig. 16.4–Fig. 16.6 creates a simple sequential-access file that might be used in an accounts receivable system to help manage the money owed by a company's credit clients. For each client, the program obtains an account number, the client's first name, the client's last name and the client's balance (i.e., the amount the client still owes the company for goods and services received in the past). The data obtained for each client constitutes a record for that client. The program uses the account number as the record key; that is, the file will be created and maintained in account-number order. [*Note*: This program assumes the user enters the records in account-number order. In a comprehensive accounts receivable system, a sorting capability would be provided so the user could enter the records in any order—the records would then be sorted and written to the file.]

Most of the programs in this chapter have a similar GUI, so this program defines class **BankUI** (Fig. 16.4) to encapsulate the GUI. (See the second sample output screen in Fig. 16.6.) Also, the program defines class **AccountRecord** (Fig. 16.5) to encapsulate the client record information (i.e., account, first name, etc.) used by the examples in this chapter. For reuse, classes **BankUI** and **AccountRecord** are defined in package **com.deitel.jhtp4.ch16**.

[*Note*: Most of the programs in this chapter use classes **BankUI** and **AccountRecord**. When you compile these classes, or any others that will be reused in this chapter, you should place the classes in a common directory. When you compile classes that use **BankUI** and **AccountRecord**, be sure to specify the **-classpath** command line argument to both **javac** and **java**, as in

```
javac -classpath .;packageLocation ClassName.java
java -classpath .;packageLocation ClassName
```

where *packageLocation* represents the common directory in which the classes of the package **com.deitel.jhtp4.ch16** reside and *ClassName* represents the class to compile or execute. Be sure to include the current directory (specified with **.**) in the class path. [Note: If your packaged classes are in a JAR file, the *packageLocation* should include the location and name of the actual JAR file.] Also, the path separator shown (**;**, which is used in Microsoft Windows) should be appropriate for your platform (such as **:** on UNIX/Linux).]

Class **BankUI** (Fig. 16.4) contains two **JButton**s and arrays of **JLabel**s and **JTextField**s. The number of **JLabel**s and **JTextField**s is set with the constructor

defined at lines 34–75. Methods **getFieldValues** (lines 116–124), **setFieldValues** (lines 104–113) and **clearFields** (lines 96–100) manipulate the text of the **JTextField**s. Methods **getFields** (lines 90–93), **getDoTask1Button** (lines 78–81) and **getDoTask2Button** (lines 84–87) return individual GUI components, so that a client program can add **ActionListener**s (for example).

```
1  // Fig. 16.4: BankUI.java
2  // A reusable GUI for the examples in this chapter.
3  package com.deitel.jhtp4.ch16;
4
5  // Java core packages
6  import java.awt.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class BankUI extends JPanel {
12
13    // label text for GUI
14    protected final static String names[] = { "Account number",
15       "First name", "Last name", "Balance",
16       "Transaction Amount" };
17
18    // GUI components; protected for future subclass access
19    protected JLabel labels[];
20    protected JTextField fields[];
21    protected JButton doTask1, doTask2;
22    protected JPanel innerPanelCenter, innerPanelSouth;
23
24    // number of text fields in GUI
25    protected int size;
26
27    // constants representing text fields in GUI
28    public static final int ACCOUNT = 0, FIRSTNAME = 1,
29       LASTNAME = 2, BALANCE = 3, TRANSACTION = 4;
30
31    // Set up GUI. Constructor argument of 4 creates four rows
32    // of GUI components. Constructor argument of 5 (used in a
33    // later program) creates five rows of GUI components.
34    public BankUI( int mySize )
35    {
36       size = mySize;
37       labels = new JLabel[ size ];
38       fields = new JTextField[ size ];
39
40       // create labels
41       for ( int count = 0; count < labels.length; count++ )
42          labels[ count ] = new JLabel( names[ count ] );
43
44       // create text fields
45       for ( int count = 0; count < fields.length; count++ )
46          fields[ count ] = new JTextField();
```

Fig. 16.4 **BankUI** contains a reusable GUI for several programs (part 1 of 3).

```
47
48          // create panel to lay out labels and fields
49          innerPanelCenter = new JPanel();
50          innerPanelCenter.setLayout( new GridLayout( size, 2 ) );
51
52          // attach labels and fields to innerPanelCenter
53          for ( int count = 0; count < size; count++ ) {
54             innerPanelCenter.add( labels[ count ] );
55             innerPanelCenter.add( fields[ count ] );
56          }
57
58          // create generic buttons; no labels or event handlers
59          doTask1 = new JButton();
60          doTask2 = new JButton();
61
62          // create panel to lay out buttons and attach buttons
63          innerPanelSouth = new JPanel();
64          innerPanelSouth.add( doTask1 );
65          innerPanelSouth.add( doTask2 );
66
67          // set layout of this container and attach panels to it
68          setLayout( new BorderLayout() );
69          add( innerPanelCenter, BorderLayout.CENTER );
70          add( innerPanelSouth, BorderLayout.SOUTH );
71
72          // validate layout
73          validate();
74
75       }  // end constructor
76
77       // return reference to generic task button doTask1
78       public JButton getDoTask1Button()
79       {
80          return doTask1;
81       }
82
83       // return reference to generic task button doTask2
84       public JButton getDoTask2Button()
85       {
86          return doTask2;
87       }
88
89       // return reference to fields array of JTextFields
90       public JTextField[] getFields()
91       {
92          return fields;
93       }
94
95       // clear content of text fields
96       public void clearFields()
97       {
98          for ( int count = 0; count < size; count++ )
99             fields[ count ].setText( "" );
```

Fig. 16.4 **BankUI** contains a reusable GUI for several programs (part 2 of 3).

```
100    }
101
102    // set text field values; throw IllegalArgumentException if
103    // incorrect number of Strings in argument
104    public void setFieldValues( String strings[] )
105       throws IllegalArgumentException
106    {
107       if ( strings.length != size )
108          throw new IllegalArgumentException( "There must be " +
109             size + " Strings in the array" );
110
111       for ( int count = 0; count < size; count++ )
112          fields[ count ].setText( strings[ count ] );
113    }
114
115    // get array of Strings with current text field contents
116    public String[] getFieldValues()
117    {
118       String values[] = new String[ size ];
119
120       for ( int count = 0; count < size; count++ )
121          values[ count ] = fields[ count ].getText();
122
123       return values;
124    }
125
126 }  // end class BankUI
```

Fig. 16.4 **BankUI** contains a reusable GUI for several programs (part 3 of 3).

Class **AccountRecord** (Fig. 16.5) implements interface ***Serializable***, which allows objects of **AccountRecord** to be used with **ObjectInputStream**s and **ObjectOutputStream**s. Interface **Serializable** is known as a *tagging interface*. Such an interface contains no methods. A class that implements this interface is *tagged* as being a **Serializable** object, which is important because an **ObjectOutputStream** will not output an object unless it *is a* **Serializable** object. In a class that implements **Serializable**, the programmer must ensure that every instance variable of the class is a **Serializable** type, or must declare particular instance variables as ***transient*** to indicate that those variables are not Serializable and they should be ignored during the serialization process. By default, all primitive type variables are transient. For non-primitive types, you must check the definition of the class (and possibly its superclasses) to ensure that the type is **Serializable**. Class **AccountRecord** contains **private** data members **account**, **firstName**, **lastName** and **balance**. This class also provides **public** "get" and "set" methods for accessing the **private** data members.

```
1  // Fig. 16.5: AccountRecord.java
2  // A class that represents one record of information.
3  package com.deitel.jhtp4.ch16;
```

Fig. 16.5 Class **AccountRecord** maintains information for one account (part 1 of 3).

```
4
5  // Java core packages
6  import java.io.Serializable;
7
8  public class AccountRecord implements Serializable {
9     private int account;
10    private String firstName;
11    private String lastName;
12    private double balance;
13
14    // no-argument constructor calls other constructor with
15    // default values
16    public AccountRecord()
17    {
18       this( 0, "", "", 0.0 );
19    }
20
21    // initialize a record
22    public AccountRecord( int acct, String first,
23       String last, double bal )
24    {
25       setAccount( acct );
26       setFirstName( first );
27       setLastName( last );
28       setBalance( bal );
29    }
30
31    // set account number
32    public void setAccount( int acct )
33    {
34       account = acct;
35    }
36
37    // get account number
38    public int getAccount()
39    {
40       return account;
41    }
42
43    // set first name
44    public void setFirstName( String first )
45    {
46       firstName = first;
47    }
48
49    // get first name
50    public String getFirstName()
51    {
52       return firstName;
53    }
54
```

Fig. 16.5 Class **AccountRecord** maintains information for one account (part 2 of 3).

```
55      // set last name
56      public void setLastName( String last )
57      {
58         lastName = last;
59      }
60
61      // get last name
62      public String getLastName()
63      {
64         return lastName;
65      }
66
67      // set balance
68      public void setBalance( double bal )
69      {
70         balance = bal;
71      }
72
73      // get balance
74      public double getBalance()
75      {
76         return balance;
77      }
78
79   }  // end class AccountRecord
```

Fig. 16.5 Class **AccountRecord** maintains information for one account (part 3 of 3).

Now, let us discuss the code that creates the sequential-access file (Fig. 16.6). In this example, we introduce class ***JFileChooser*** (package **javax.swing**) for selecting files (as on the second screen in Fig. 16.6). Line 103 constructs a **JFileChooser** instance and assigns it to reference **fileChooser**. Lines 104–105 call method ***setFileSelectionMode*** to specify what the user can select from the **fileChooser**. For this program, we use **JFileChooser** **static** constant ***FILES_ONLY*** to indicate that only files can be selected. Other **static** constants include ***FILES_AND_DIRECTORIES*** and ***DIRECTORIES_ONLY***.

```
1   // Fig. 16.6: CreateSequentialFile.java
2   // Demonstrating object output with class ObjectOutputStream.
3   // The objects are written sequentially to a file.
4
5   // Java core packages
6   import java.io.*;
7   import java.awt.*;
8   import java.awt.event.*;
9
10  // Java extension packages
11  import javax.swing.*;
12
```

Fig. 16.6 Creating a sequential file (part 1 of 6).

```
13 // Deitel packages
14 import com.deitel.jhtp4.ch16.BankUI;
15 import com.deitel.jhtp4.ch16.AccountRecord;
16
17 public class CreateSequentialFile extends JFrame {
18    private ObjectOutputStream output;
19    private BankUI userInterface;
20    private JButton enterButton, openButton;
21
22    // set up GUI
23    public CreateSequentialFile()
24    {
25       super( "Creating a Sequential File of Objects" );
26
27       // create instance of reusable user interface
28       userInterface = new BankUI( 4 );  // four textfields
29       getContentPane().add(
30          userInterface, BorderLayout.CENTER );
31
32       // get reference to generic task button doTask1 in BankUI
33       // and configure button for use in this program
34       openButton = userInterface.getDoTask1Button();
35       openButton.setText( "Save into File ..." );
36
37       // register listener to call openFile when button pressed
38       openButton.addActionListener(
39
40          // anonymous inner class to handle openButton event
41          new ActionListener() {
42
43             // call openFile when button pressed
44             public void actionPerformed( ActionEvent event )
45             {
46                openFile();
47             }
48
49          }  // end anonymous inner class
50
51       ); // end call to addActionListener
52
53       // get reference to generic task button doTask2 in BankUI
54       // and configure button for use in this program
55       enterButton = userInterface.getDoTask2Button();
56       enterButton.setText( "Enter" );
57       enterButton.setEnabled( false );  // disable button
58
59       // register listener to call addRecord when button pressed
60       enterButton.addActionListener(
61
62          // anonymous inner class to handle enterButton event
63          new ActionListener() {
64
```

Fig. 16.6 Creating a sequential file (part 2 of 6).

```
65             // call addRecord when button pressed
66             public void actionPerformed( ActionEvent event )
67             {
68                addRecord();
69             }
70
71          }  // end anonymous inner class
72
73       ); // end call to addActionListener
74
75       // register window listener to handle window closing event
76       addWindowListener(
77
78          // anonymous inner class to handle windowClosing event
79          new WindowAdapter() {
80
81             // add current record in GUI to file, then close file
82             public void windowClosing( WindowEvent event )
83             {
84                if ( output != null )
85                   addRecord();
86
87                closeFile();
88             }
89
90          }  // end anonymous inner class
91
92       ); // end call to addWindowListener
93
94       setSize( 300, 200 );
95       show();
96
97    }  // end CreateSequentialFile constructor
98
99    // allow user to specify file name
100   private void openFile()
101   {
102      // display file dialog, so user can choose file to open
103      JFileChooser fileChooser = new JFileChooser();
104      fileChooser.setFileSelectionMode(
105         JFileChooser.FILES_ONLY );
106
107      int result = fileChooser.showSaveDialog( this );
108
109      // if user clicked Cancel button on dialog, return
110      if ( result == JFileChooser.CANCEL_OPTION )
111         return;
112
113      // get selected file
114      File fileName = fileChooser.getSelectedFile();
115
```

Fig. 16.6 Creating a sequential file (part 3 of 6).

```
116         // display error if invalid
117         if ( fileName == null ||
118              fileName.getName().equals( "" ) )
119            JOptionPane.showMessageDialog( this,
120               "Invalid File Name", "Invalid File Name",
121               JOptionPane.ERROR_MESSAGE );
122
123         else {
124
125            // open file
126            try {
127               output = new ObjectOutputStream(
128                  new FileOutputStream( fileName ) );
129
130               openButton.setEnabled( false );
131               enterButton.setEnabled( true );
132            }
133
134            // process exceptions from opening file
135            catch ( IOException ioException ) {
136               JOptionPane.showMessageDialog( this,
137                  "Error Opening File", "Error",
138                  JOptionPane.ERROR_MESSAGE );
139            }
140         }
141
142      }  // end method openFile
143
144      // close file and terminate application
145      private void closeFile()
146      {
147         // close file
148         try {
149            output.close();
150
151            System.exit( 0 );
152         }
153
154         // process exceptions from closing file
155         catch( IOException ioException ) {
156            JOptionPane.showMessageDialog( this,
157               "Error closing file", "Error",
158               JOptionPane.ERROR_MESSAGE );
159            System.exit( 1 );
160         }
161      }
162
163      // add record to file
164      public void addRecord()
165      {
166         int accountNumber = 0;
167         AccountRecord record;
168         String fieldValues[] = userInterface.getFieldValues();
```

Fig. 16.6 Creating a sequential file (part 4 of 6).

```
169
170         // if account field value is not empty
171         if ( ! fieldValues[ BankUI.ACCOUNT ].equals( "" ) ) {
172
173            // output values to file
174            try {
175               accountNumber = Integer.parseInt(
176                  fieldValues[ BankUI.ACCOUNT ] );
177
178               if ( accountNumber > 0 ) {
179
180                  // create new record
181                  record = new AccountRecord( accountNumber,
182                     fieldValues[ BankUI.FIRSTNAME ],
183                     fieldValues[ BankUI.LASTNAME ],
184                     Double.parseDouble(
185                        fieldValues[ BankUI.BALANCE ] ) );
186
187                  // output record and flush buffer
188                  output.writeObject( record );
189                  output.flush();
190               }
191
192               // clear textfields
193               userInterface.clearFields();
194            }
195
196            // process invalid account number or balance format
197            catch ( NumberFormatException formatException ) {
198               JOptionPane.showMessageDialog( this,
199                  "Bad account number or balance",
200                  "Invalid Number Format",
201                  JOptionPane.ERROR_MESSAGE );
202            }
203
204            // process exceptions from file output
205            catch ( IOException ioException ) {
206               closeFile();
207            }
208
209         }  // end if
210
211      }  // end method addRecord
212
213      // execute application; CreateSequentialFile constructor
214      // displays window
215      public static void main( String args[] )
216      {
217         new CreateSequentialFile();
218      }
219
220   }  // end class CreateSequentialFile
```

Fig. 16.6 Creating a sequential file (part 5 of 6).

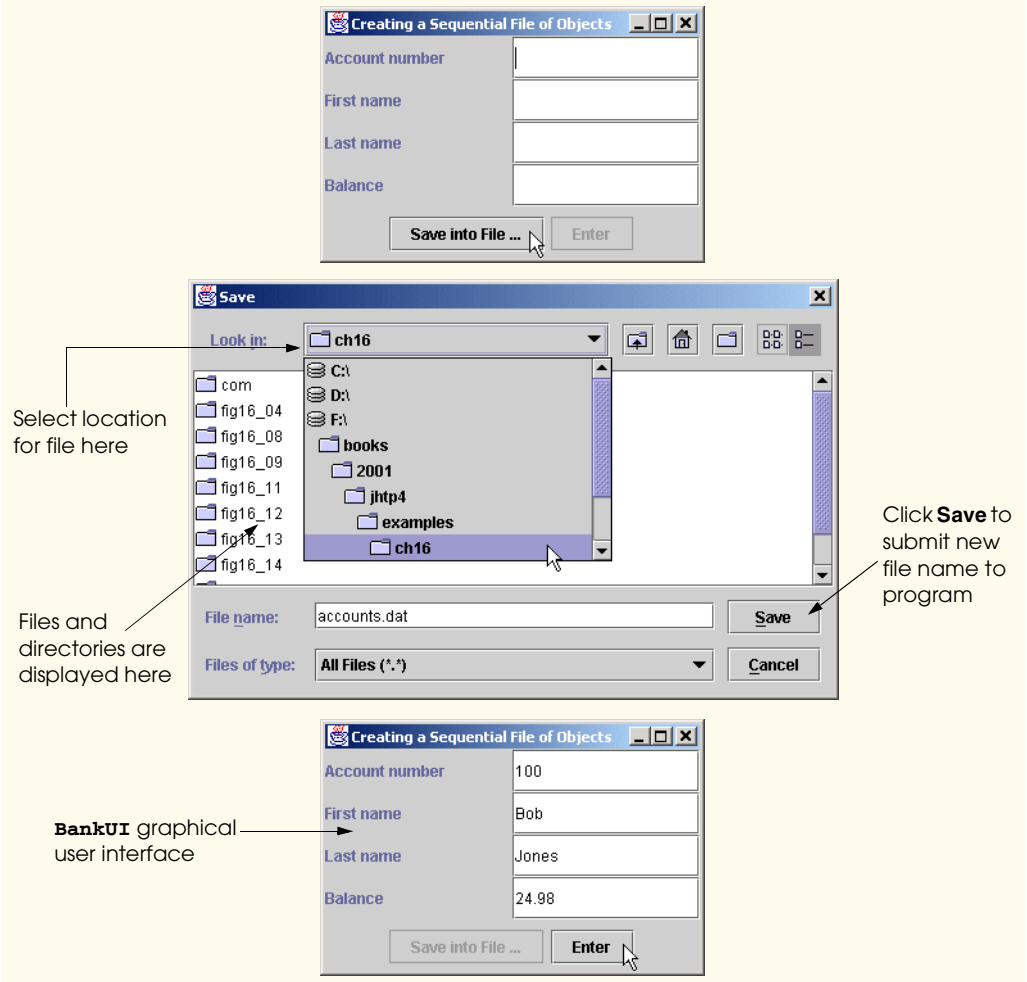


Fig. 16.6 Creating a sequential file (part 6 of 6).

Line 107 calls method ***showSaveDialog*** to display the **`JFileChooser`** dialog titled **Save**. Argument **`this`** specifies the **`JFileChooser`** dialog's *parent* window, which determines the position of the dialog on the screen. If **`null`** is passed, the dialog is displayed in the center of the window; otherwise, the dialog is centered over the application window. When displayed, a **`JFileChooser`** dialog does not allow the user to interact with any other program window until the user closes the **`JFileChooser`** dialog by clicking **Save** or **Cancel**. Dialogs that behave in this fashion are called *modal* dialogs. The user selects the drive, directory and file name, then clicks **Save**. Method **`showSaveDialog`** returns an integer specifying which button the user clicked (**Save** or **Cancel**) to close the dialog. Line 110 tests whether the user clicked **Cancel** by comparing **`result`** to **`static`** constant ***`CANCEL_OPTION`***. If so, the method returns.

Line 114 retrieves the file the user selected by calling method ***getSelectedFile***, which returns an object of type **File** that encapsulates information about the file (e.g., name and location), but does not represent the contents of the file. This **File** object does not open the file. We assign this **File** object to the reference **fileName**.

As stated previously, a program opens a file by creating an object of stream class **FileInputStream** or **FileOutputStream**. In this example, the file is to be opened for output, so the program creates a **FileOutputStream**. One argument is passed to the **FileOutputStream**'s constructor—a **File** object. Existing files opened for output are *truncated*—all data in the file is discarded.

Common Programming Error 16.1

It is a logic error to open an existing file for output when, in fact, the user wants to preserve the file. The contents of the file are discarded without warning.

Class **FileOutputStream** provides methods for writing **byte** arrays and individual **byte**s to a file. For this program, we need to write objects to a file—a capability not provided by **FileOutputStream**. The solution to this problem is a technique called *chaining of stream objects*—the ability to add the services of one stream to another. To chain an **ObjectOutputStream** to the **FileOutputStream**, we pass the **FileOutputStream** object to the **ObjectOutputStream**'s constructor (lines 127–128). The constructor could throw an ***IOException*** if a problem occurs during opening of the file (e.g., when a file is opened for writing on a drive with insufficient space, a read-only file is opened for writing or a nonexistent file is opened for reading). If so, the program displays a **JOptionPane**. If construction of the two streams does not throw an **IOException**, the file is open. Then, reference **output** can be used to write objects to the file.

The program assumes data is input correctly and in the proper record number order. The user populates the **JTextField**s and clicks **Enter** to write the data to the file. The **Enter** button's **actionPerformed** method (lines 66–69) calls our method **addRecord** (lines 164–211) to perform the write operation. Line 188 calls method ***writeObject*** to write the **record** object to file. Line 189 calls method ***flush*** to ensure that any data stored in memory is written to the file immediately.

When the user clicks the close box (the **X** in the window's top-right corner), the program calls method **windowClosing** (lines 82–88), which compares **output** to **null** (line 84). If **output** is not **null**, the stream is open and methods **addRecord** and **closeFile** (lines 145–161) are called. Method **closeFile** calls method ***close*** for **output** to close the file.

Performance Tip 16.3

Always release resources explicitly and at the earliest possible moment at which it is determined that the resource is no longer needed. This makes the resource immediately available to be reused by your program or by another program, thus improving resource utilization.

When using chained stream objects, the outermost object (the **ObjectOutputStream** in this example) should be used to close the file.

Performance Tip 16.4

Explicitly close each file as soon as it is known that the program will not reference the file again. This can reduce resource usage in a program that will continue executing long after it no longer needs to be referencing a particular file. This practice also improves program clarity.

In the sample execution for the program of Fig. 16.6, we entered information for five accounts (see Fig. 16.7). The program does not show how the data records actually appear in the file. To verify that the file has been created successfully, in the next section we create a program to read the file.

16.5 Reading Data from a Sequential-Access File

Data are stored in files so that they may be retrieved for processing when needed. The previous section demonstrated how to create a file for sequential access. In this section, we discuss how to read data sequentially from a file.

The program of Fig. 16.8 reads records from a file created by the program of Fig. 16.6 and displays the contents of the records. The program opens the file for input by creating a **`FileInputStream`** object. The program specifies the name of the file to open as an argument to the **`FileInputStream`** constructor. In Fig. 16.6, we wrote objects to the file, using an **`ObjectOutputStream`** object. Data must be read from the file in the same format in which it was written to the file. Therefore, we use an **`ObjectInputStream`** chained to a **`FileInputStream`** in this program. Note that the third sample screen capture shows the GUI displaying the last record in the file.

Sample Data

100	Bob	Jones	24.98
200	Steve	Doe	-345.67
300	Pam	White	0.00
400	Sam	Stone	-42.16
500	Sue	Rich	224.62

Fig. 16.7 Sample data for the program of Fig. 16.6.

```
1  // Fig. 16.8: ReadSequentialFile.java
2  // This program reads a file of objects sequentially
3  // and displays each record.
4
5  // Java core packages
6  import java.io.*;
7  import java.awt.*;
8  import java.awt.event.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 // Deitel packages
14 import com.deitel.jhtp4.ch16.*;
15
16 public class ReadSequentialFile extends JFrame {
17    private ObjectInputStream input;
```

Fig. 16.8 Reading a sequential file (part 1 of 6).

```
18    private BankUI userInterface;
19    private JButton nextButton, openButton;
20
21    // Constructor -- initialize the Frame
22    public ReadSequentialFile()
23    {
24       super( "Reading a Sequential File of Objects" );
25
26       // create instance of reusable user interface
27       userInterface = new BankUI( 4 );  // four textfields
28       getContentPane().add(
29          userInterface, BorderLayout.CENTER );
30
31       // get reference to generic task button doTask1 from BankUI
32       openButton = userInterface.getDoTask1Button();
33       openButton.setText( "Open File" );
34
35       // register listener to call openFile when button pressed
36       openButton.addActionListener(
37
38          // anonymous inner class to handle openButton event
39          new ActionListener() {
40
41             // close file and terminate application
42             public void actionPerformed( ActionEvent event )
43             {
44                openFile();
45             }
46
47          }  // end anonymous inner class
48
49       ); // end call to addActionListener
50
51       // register window listener for window closing event
52       addWindowListener(
53
54          // anonymous inner class to handle windowClosing event
55          new WindowAdapter() {
56
57             // close file and terminate application
58             public void windowClosing( WindowEvent event )
59             {
60                if ( input != null )
61                   closeFile();
62
63                System.exit( 0 );
64             }
65
66          }  // end anonymous inner class
67
68       ); // end call to addWindowListener
69
```

Fig. 16.8 Reading a sequential file (part 2 of 6).

```
70          // get reference to generic task button doTask2 from BankUI
71          nextButton = userInterface.getDoTask2Button();
72          nextButton.setText( "Next Record" );
73          nextButton.setEnabled( false );
74
75          // register listener to call readRecord when button pressed
76          nextButton.addActionListener(
77
78             // anonymous inner class to handle nextRecord event
79             new ActionListener() {
80
81                // call readRecord when user clicks nextRecord
82                public void actionPerformed( ActionEvent event )
83                {
84                   readRecord();
85                }
86
87             }  // end anonymous inner class
88
89          ); // end call to addActionListener
90
91          pack();
92          setSize( 300, 200 );
93          show();
94
95       }  // end ReadSequentialFile constructor
96
97       // enable user to select file to open
98       private void openFile()
99       {
100         // display file dialog so user can select file to open
101         JFileChooser fileChooser = new JFileChooser();
102         fileChooser.setFileSelectionMode(
103            JFileChooser.FILES_ONLY );
104
105         int result = fileChooser.showOpenDialog( this );
106
107         // if user clicked Cancel button on dialog, return
108         if ( result == JFileChooser.CANCEL_OPTION )
109            return;
110
111         // obtain selected file
112         File fileName = fileChooser.getSelectedFile();
113
114         // display error if file name invalid
115         if ( fileName == null ||
116              fileName.getName().equals( "" ) )
117            JOptionPane.showMessageDialog( this,
118               "Invalid File Name", "Invalid File Name",
119               JOptionPane.ERROR_MESSAGE );
120
121         else {
122
```

Fig. 16.8 Reading a sequential file (part 3 of 6).

```
123          // open file
124          try {
125             input = new ObjectInputStream(
126                new FileInputStream( fileName ) );
127
128             openButton.setEnabled( false );
129             nextButton.setEnabled( true );
130          }
131
132          // process exceptions opening file
133          catch ( IOException ioException ) {
134             JOptionPane.showMessageDialog( this,
135                "Error Opening File", "Error",
136                JOptionPane.ERROR_MESSAGE );
137          }
138
139       }  // end else
140
141    }  // end method openFile
142
143    // read record from file
144    public void readRecord()
145    {
146       AccountRecord record;
147
148       // input the values from the file
149       try {
150          record = ( AccountRecord ) input.readObject();
151
152          // create array of Strings to display in GUI
153          String values[] = {
154             String.valueOf( record.getAccount() ),
155             record.getFirstName(),
156             record.getLastName(),
157             String.valueOf( record.getBalance() ) };
158
159          // display record contents
160          userInterface.setFieldValues( values );
161       }
162
163       // display message when end-of-file reached
164       catch ( EOFException endOfFileException ) {
165          nextButton.setEnabled( false );
166
167          JOptionPane.showMessageDialog( this,
168             "No more records in file",
169             "End of File", JOptionPane.ERROR_MESSAGE );
170       }
171
172       // display error message if cannot read object
173       // because class not found
174       catch ( ClassNotFoundException classNotFoundException ) {
175          JOptionPane.showMessageDialog( this,
```

Fig. 16.8 Reading a sequential file (part 4 of 6).

```
176                "Unable to create object",
177                "Class Not Found", JOptionPane.ERROR_MESSAGE );
178          }
179
180          // display error message if cannot read
181          // due to problem with file
182          catch ( IOException ioException ) {
183             JOptionPane.showMessageDialog( this,
184                "Error during read from file",
185                "Read Error", JOptionPane.ERROR_MESSAGE );
186          }
187       }
188
189       // close file and terminate application
190       private void closeFile()
191       {
192          // close file and exit
193          try {
194             input.close();
195             System.exit( 0 );
196          }
197
198          // process exception while closing file
199          catch ( IOException ioException ) {
200             JOptionPane.showMessageDialog( this,
201                "Error closing file",
202                "Error", JOptionPane.ERROR_MESSAGE );
203
204             System.exit( 1 );
205          }
206       }
207
208       // execute application; ReadSequentialFile constructor
209       // displays window
210       public static void main( String args[] )
211       {
212          new ReadSequentialFile();
213       }
214
215    }  // end class ReadSequentialFile
```

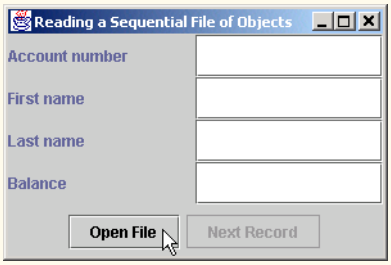


Fig. 16.8 Reading a sequential file (part 5 of 6).

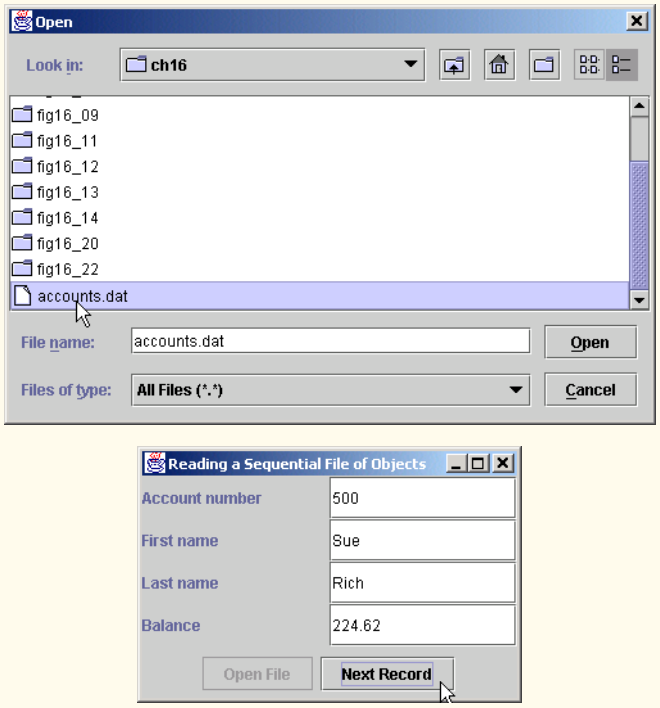


Fig. 16.8 Reading a sequential file (part 6 of 6).

Most of the code in this example is similar to Fig. 16.6, so we discuss only the key lines of code that are different. Line 105 calls **`JFileChooser`** method ***`showOpenDialog`*** to display the **Open** dialog (second screen capture in Fig. 16.8). The behavior and GUI are the same as the dialog displayed by **`showSaveDialog`**, except that the title of the dialog and the **Save** button are both replaced with **Open**.

Lines 125–126 create a **`ObjectInputStream`** object and assign it to **`input`**. The **`File fileName`** is passed to the **`FileInputStream`** constructor to open the file.

The program reads a record from the file each time the user clicks the **Next Record** button. Line 84 in **Next Record**'s **`actionPerformed`** method calls method **`readRecord`** (lines 144–187) to read one record from the file. Line 150 calls method ***`readObject`*** to read an **`Object`** from the **`ObjectInputStream`**. To use **`AccountRecord`** specific methods, we cast the returned **`Object`** to type **`AccountRecord`**. If the end-of-file marker is reached during reading, **`readObject`** throws an ***`EndOfFileException`***.

To retrieve data sequentially from a file, programs normally start reading from the beginning of the file and read all the data consecutively until the desired data are found. It might be necessary to process the file sequentially several times (from the beginning of the file) during the execution of a program. Class **`FileInputStream`** does not provide the ability to reposition to the beginning of the file to read the file again unless the program closes the file and reopens it. Class **`RandomAccessFile`** objects can reposition to the beginning of the file. Class **`RandomAccessFile`** provides all the capabilities of the

classes **FileInputStream**, **FileOutputStream**, **DataInputStream** and **DataOutputStream** and adds several other methods, including a ***seek*** that repositions the *file-position pointer* (the byte number of the next byte in the file to be read or written) to any position in the file. However, class **RandomAccessFile** cannot read and write entire objects.

Performance Tip 16.5

The process of closing and reopening a file for the purpose of positioning the file-position pointer back to the beginning of a file is a time-consuming task for the computer. If this is done frequently, it can slow the performance of your program.

The program of Fig. 16.9 enables a credit manager to display the account information for those customers with zero balances (i.e., customers who do not owe the company any money), credit balances (i.e., customers to whom the company owes money) and debit balances (i.e., customers who owe the company money for goods and services received in the past).

The program displays buttons that allow a credit manager to obtain credit information. The **Credit balances** button produces a list of accounts with credit balances. The **Debit balances** button produces a list of accounts with debit balances. The **Zero balances** button produces a list of accounts with zero balances.

Records are displayed in a **JTextArea** called **recordDisplayArea**. The record information is collected by reading through the entire file and determining, for each record, whether it satisfies the criteria for the account type selected by the credit manager. Clicking one of the balance buttons sets variable **accountType** (line 274) to the clicked button's text (e.g., **Zero balances**) and invokes method **readRecords** (191–238), which loops through the file and reads every record. Line 208 of method **readRecords** calls method **shouldDisplay** (241–259) to determine whether the current record satisfies the account type requested. If **shouldDisplay** returns **true**, the program appends the account information for the current record to the **JTextArea recordDisplay**. When the end-of-file marker is reached, line 219 calls method **closeFile** to close the file.

```
1  // Fig. 16.9: CreditInquiry.java
2  // This program reads a file sequentially and displays the
3  // contents in a text area based on the type of account the
4  // user requests (credit balance, debit balance or
5  // zero balance).
6
7  // Java core packages
8  import java.io.*;
9  import java.awt.*;
10 import java.awt.event.*;
11 import java.text.DecimalFormat;
12
13 // Java extension packages
14 import javax.swing.*;
15
16 // Deitel packages
17 import com.deitel.jhtp4.ch16.AccountRecord;
```

Fig. 16.9 Credit inquiry program (part 1 of 7).

```
18
19 public class CreditInquiry extends JFrame {
20    private JTextArea recordDisplayArea;
21    private JButton openButton,
22       creditButton, debitButton, zeroButton;
23    private JPanel buttonPanel;
24
25    private ObjectInputStream input;
26    private FileInputStream fileInput;
27    private File fileName;
28    private String accountType;
29
30    // set up GUI
31    public CreditInquiry()
32    {
33       super( "Credit Inquiry Program" );
34
35       Container container = getContentPane();
36
37       // set up panel for buttons
38       buttonPanel = new JPanel();
39
40       // create and configure button to open file
41       openButton = new JButton( "Open File" );
42       buttonPanel.add( openButton );
43
44       // register openButton listener
45       openButton.addActionListener(
46
47          // anonymous inner class to handle openButton event
48          new ActionListener() {
49
50             // open file for processing
51             public void actionPerformed( ActionEvent event )
52             {
53                openFile( true );
54             }
55
56          }  // end anonymous inner class
57
58       ); // end call to addActionListener
59
60       // create and configure button to get
61       // accounts with credit balances
62       creditButton = new JButton( "Credit balances" );
63       buttonPanel.add( creditButton );
64       creditButton.addActionListener( new ButtonHandler() );
65
66       // create and configure button to get
67       // accounts with debit balances
68       debitButton = new JButton( "Debit balances" );
69       buttonPanel.add( debitButton );
70       debitButton.addActionListener( new ButtonHandler() );
```

Fig. 16.9 Credit inquiry program (part 2 of 7).

```
71
72          // create and configure button to get
73          // accounts with credit balances
74          zeroButton = new JButton( "Zero balances" );
75          buttonPanel.add( zeroButton );
76          zeroButton.addActionListener( new ButtonHandler() );
77
78          // set up display area
79          recordDisplayArea = new JTextArea();
80          JScrollPane scroller =
81             new JScrollPane( recordDisplayArea );
82
83          // attach components to content pane
84          container.add( scroller, BorderLayout.CENTER );
85          container.add( buttonPanel, BorderLayout.SOUTH );
86
87          // disable creditButton, debitButton and zeroButton
88          creditButton.setEnabled( false );
89          debitButton.setEnabled( false );
90          zeroButton.setEnabled( false );
91
92          // register window listener
93          addWindowListener(
94
95             // anonymous inner class for windowClosing event
96             new WindowAdapter() {
97
98                // close file and terminate program
99                public void windowClosing( WindowEvent event )
100               {
101                  closeFile();
102                  System.exit( 0 );
103               }
104
105            }  // end anonymous inner class
106
107         ); // end call to addWindowListener
108
109         // pack components and display window
110         pack();
111         setSize( 600, 250 );
112         show();
113
114      }  // end CreditInquiry constructor
115
116      // enable user to choose file to open first time;
117      // otherwise, reopen chosen file
118      private void openFile( boolean firstTime )
119      {
120         if ( firstTime ) {
121
122            // display dialog, so user can choose file
123            JFileChooser fileChooser = new JFileChooser();
```

Fig. 16.9 Credit inquiry program (part 3 of 7).

```
124            fileChooser.setFileSelectionMode(
125               JFileChooser.FILES_ONLY );
126
127            int result = fileChooser.showOpenDialog( this );
128
129            // if user clicked Cancel button on dialog, return
130            if ( result == JFileChooser.CANCEL_OPTION )
131               return;
132
133            // obtain selected file
134            fileName = fileChooser.getSelectedFile();
135         }
136
137         // display error if file name invalid
138         if ( fileName == null ||
139              fileName.getName().equals( "" ) )
140            JOptionPane.showMessageDialog( this,
141               "Invalid File Name", "Invalid File Name",
142               JOptionPane.ERROR_MESSAGE );
143
144         else {
145
146            // open file
147            try {
148
149               // close file from previous operation
150               if ( input != null )
151                  input.close();
152
153               fileInput = new FileInputStream( fileName );
154               input = new ObjectInputStream( fileInput );
155               openButton.setEnabled( false );
156               creditButton.setEnabled( true );
157               debitButton.setEnabled( true );
158               zeroButton.setEnabled( true );
159            }
160
161            // catch problems manipulating file
162            catch ( IOException ioException ) {
163               JOptionPane.showMessageDialog( this,
164                  "File does not exist", "Invalid File Name",
165                  JOptionPane.ERROR_MESSAGE );
166            }
167         }
168
169      }  // end method openFile
170
171      // close file before application terminates
172      private void closeFile()
173      {
174         // close file
175         try {
176            input.close();
```

Fig. 16.9 Credit inquiry program (part 4 of 7).

```
177         }
178
179         // process exception from closing file
180         catch ( IOException ioException ) {
181            JOptionPane.showMessageDialog( this,
182               "Error closing file",
183               "Error", JOptionPane.ERROR_MESSAGE );
184
185            System.exit( 1 );
186         }
187      }
188
189      // read records from file and display only records of
190      // appropriate type
191      private void readRecords()
192      {
193         AccountRecord record;
194         DecimalFormat twoDigits = new DecimalFormat( "0.00" );
195         openFile( false );
196
197         // read records
198         try {
199            recordDisplayArea.setText( "The accounts are:\n" );
200
201            // input the values from the file
202            while ( true ) {
203
204               // read one AccountRecord
205               record = ( AccountRecord ) input.readObject();
206
207               // if proper acount type, display record
208               if ( shouldDisplay( record.getBalance() ) )
209                  recordDisplayArea.append( record.getAccount() +
210                     "\t" + record.getFirstName() + "\t" +
211                     record.getLastName() + "\t" +
212                     twoDigits.format( record.getBalance() ) +
213                     "\n" );
214            }
215         }
216
217         // close file when end-of-file reached
218         catch ( EOFException eofException ) {
219            closeFile();
220         }
221
222         // display error if cannot read object
223         // because class not found
224         catch ( ClassNotFoundException classNotFound ) {
225            JOptionPane.showMessageDialog( this,
226               "Unable to create object",
227               "Class Not Found", JOptionPane.ERROR_MESSAGE );
228         }
229
```

Fig. 16.9 Credit inquiry program (part 5 of 7).

```
230         // display error if cannot read
231         // because problem with file
232         catch ( IOException ioException ) {
233            JOptionPane.showMessageDialog( this,
234               "Error reading from file",
235               "Error", JOptionPane.ERROR_MESSAGE );
236         }
237
238      }  // end method readRecords
239
240      // uses record ty to determine if a record should be displayed
241      private boolean shouldDisplay( double balance )
242      {
243         if ( accountType.equals( "Credit balances" ) &&
244            balance < 0 )
245
246            return true;
247
248         else if ( accountType.equals( "Debit balances" ) &&
249            balance > 0 )
250
251            return true;
252
253         else if ( accountType.equals( "Zero balances" ) &&
254            balance == 0 )
255
256            return true;
257
258         return false;
259      }
260
261      // execute application
262      public static void main( String args[] )
263      {
264         new CreditInquiry();
265      }
266
267      // private inner class for creditButton, debitButton and
268      // zeroButton event handling
269      private class ButtonHandler implements ActionListener {
270
271         // read records from file
272         public void actionPerformed( ActionEvent event )
273         {
274            accountType = event.getActionCommand();
275            readRecords();
276         }
277
278      }  // end class ButtonHandler
279
280   }  // end class CreditInquiry
```

Fig. 16.9 Credit inquiry program (part 6 of 7).

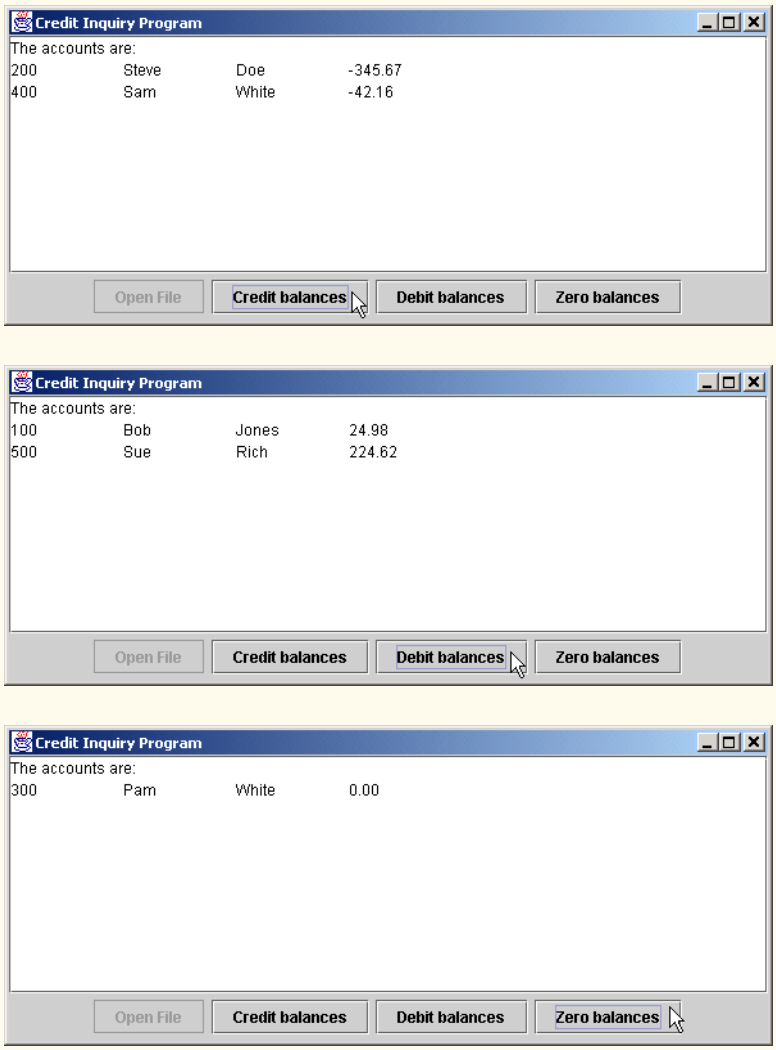


Fig. 16.9 Credit inquiry program (part 7 of 7).

16.6 Updating Sequential-Access Files

Data that is formatted and written to a sequential-access file as shown in Section 16.4 cannot be modified without reading and writing all the data in the file. For example, if the name **`White`** needed to be changed to **`Worthington`**, the old name cannot simply be overwritten. Such updating can be done, but it is awkward. To make the preceding name change, the records before **`White`** in a sequential-access file could be copied to a new file, the updated record would then be written to the new file, and the records after **`White`** would be copied to the new file. This requires processing every record in the file to update one record. If many records are being updated in one pass of the file, this technique can be acceptable.

16.7 Random-Access Files

So far, we have seen how to create sequential-access files and to search through them to locate particular information. Sequential-access files are inappropriate for so-called "*instant-access" applications*, in which a particular record of information must be located immediately. Some popular instant-access applications are airline reservation systems, banking systems, point-of-sale systems, automated-teller machines and other kinds of *transaction-processing systems* that require rapid access to specific data. The bank at which you have your account might have hundreds of thousands or even millions of other customers, yet, when you use an automated teller machine, the bank determines in seconds whether your account has sufficient funds for the transaction. This kind of instant access is possible with *random-access files*. A program can access individual records of a random-access file directly (and quickly) without searching through other records. Random-access files are sometimes called *direct-access files*.

As we have said, Java does not impose structure on a file, so an application that wants to use random-access files must create them. Several techniques can be used to create random-access files. Perhaps the simplest is to require that all records in a file be of the same fixed length.

Using fixed-length records makes it easy for a program to calculate (as a function of the record size and the record key) the exact location of any record relative to the beginning of the file. We will soon see how this facilitates immediate access to specific records, even in large files.

Figure 16.10 illustrates Java's view of a random-access file composed of fixed-length records (each record in this figure is 100 bytes long). A random-access file is like a railroad train with many cars—some empty, some with contents.

A program can insert data in a random-access file without destroying other data in the file. Also, a program can update or delete data stored previously without rewriting the entire file. In the following sections, we explain how to create a random-access file, enter data, read the data both sequentially and randomly, update the data and delete data no longer needed.

16.8 Creating a Random-Access File

`RandomAccessFile` objects have all the capabilities of **`DataInputStream`** and **`DataOutputStream`** objects discussed earlier. When a program associates an object of class **`RandomAccessFile`** with a file, the program reads or writes data beginning at the location in the file specified by the *file-position pointer* and manipulates all data as primitive data types. When writing an **`int`** value, 4 bytes are output to the file. When reading a **`double`** value, 8 bytes are input from the file. The size of the data types is guaranteed, because Java has fixed sizes for all primitive data types regardless of the computing platform.

Random-access file-processing programs rarely write a single field to a file. Normally, they write one object at a time, as we show in the following examples.

Consider the following problem statement:

> *Create a transaction-processing program capable of storing up to 100 fixed-length records for a company that can have up to 100 customers. Each record should consist of an account number that will be used as the record key, a last name, a first name and a balance. The program should be able to update an account, insert a new account and delete an account.*

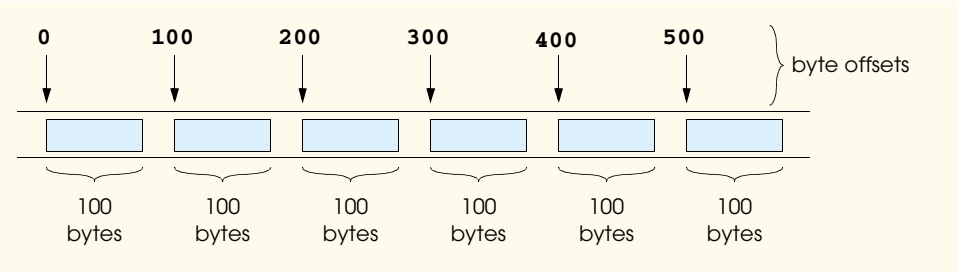


Fig. 16.10 Java's view of a random-access file.

The next several sections introduce the techniques necessary to create this credit-processing program. Figure 16.11 contains the **RandomAccessAccountRecord** class that is used by the next four programs for both reading records from and writing records to a file.

```
1  // Fig. 16.11: RandomAccessAccountRecord.java
2  // Subclass of AccountRecord for random access file programs.
3  package com.deitel.jhtp4.ch16;
4
5  // Java core packages
6  import java.io.*;
7
8  public class RandomAccessAccountRecord extends AccountRecord {
9
10    // no-argument constructor calls other constructor
11    // with default values
12    public RandomAccessAccountRecord()
13    {
14       this( 0, "", "", 0.0 );
15    }
16
17    // initialize a RandomAccessAccountRecord
18    public RandomAccessAccountRecord( int account,
19       String firstName, String lastName, double balance )
20    {
21       super( account, firstName, lastName, balance );
22    }
23
24    // read a record from specified RandomAccessFile
25    public void read( RandomAccessFile file ) throws IOException
26    {
27       setAccount( file.readInt() );
28       setFirstName( padName( file ) );
29       setLastName( padName( file ) );
30       setBalance( file.readDouble() );
31    }
32
```

Fig. 16.11 **RandomAccessAccountRecord** class used in the random-access file programs (part 1 of 2).

```
33     // ensure that name is proper length
34     private String padName( RandomAccessFile file )
35        throws IOException
36     {
37        char name[] = new char[ 15 ], temp;
38
39        for ( int count = 0; count < name.length; count++ ) {
40           temp = file.readChar();
41           name[ count ] = temp;
42        }
43
44        return new String( name ).replace( '\0', ' ' );
45     }
46
47     // write a record to specified RandomAccessFile
48     public void write( RandomAccessFile file ) throws IOException
49     {
50        file.writeInt( getAccount() );
51        writeName( file, getFirstName() );
52        writeName( file, getLastName() );
53        file.writeDouble( getBalance() );
54     }
55
56     // write a name to file; maximum of 15 characters
57     private void writeName( RandomAccessFile file, String name )
58        throws IOException
59     {
60        StringBuffer buffer = null;
61
62        if ( name != null )
63           buffer = new StringBuffer( name );
64        else
65           buffer = new StringBuffer( 15 );
66
67        buffer.setLength( 15 );
68        file.writeChars( buffer.toString() );
69     }
70
71     // NOTE: This method contains a hard coded value for the
72     // size of a record of information.
73     public static int size()
74     {
75        return 72;
76     }
77
78  }  // end class RandomAccessAccountRecord
```

Fig. 16.11 **RandomAccessAccountRecord** class used in the random-access file programs (part 2 of 2).

Class **RandomAccessAccountRecord** inherits **AccountRecord**'s (Fig. 16.5) implementation, which includes **private** instance variables—**account**, **lastName**, **firstName** and **balance**—as well as their **public** *set* and *get* methods.

Method **read** (lines 25–31) reads one record from the **RandomAccessFile** object passed as an argument. Methods ***readInt*** (line 27) and ***readDouble*** (line 30) read the **account** and **balance**, respectively. Method **read** calls **private** method **padName** (lines 34–45) twice to obtain the first and last names. Method **padName** reads fifteen characters from the **RandomAccessFile** and returns a **String**. If a name is shorter than 15 characters, the program fills each extra character with a null byte (**'\0'**). Swing components, such as **JTextField**s, cannot display null byte characters (which are displayed instead as rectangles). Line 44 solves this problem by replacing null bytes with spaces.

Method **write** (48–54) outputs one record to the **RandomAccessFile** object passed in as an argument. This method uses method ***writeInt*** to output the integer **account**, method ***writeChars*** (called from utility method **writeName**) to output the **firstName** and **lastName** character arrays and method ***writeDouble*** to output the **double balance**. [*Note*: In order to ensure that all records in the **RandomAccessFile** have the same size, we write exactly 15 characters for the first name and exactly 15 characters for the last name.] Method **writeName** (lines 57–69) performs the write operations for the first and last name.

Figure 16.12 illustrates opening a random-access file and writing data to the disk. This program writes 100 **RandomAccessAccountRecord**s, using method **write** (Fig. 16.11). Each **RandomAccessAccountRecord** object contains **0** for the account number, **null** for the last name, **null** for the first name and **0.0** for the balance. The file is initialized to create the proper amount of "empty" space in which the account data will be stored and to enable us to determine in subsequent programs whether each record is empty or contains data.

```
1  // Fig. 16.12: CreateRandomFile.java
2  // This program creates a random access file sequentially
3  // by writing 100 empty records to disk.
4
5  // Java core packages
6  import java.io.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 // Deitel packages
12 import com.deitel.jhtp4.ch16.RandomAccessAccountRecord;
13
14 public class CreateRandomFile {
15
16    // enable user to select file to open
17    private void createFile()
18    {
19       // display dialog so user can choose file
20       JFileChooser fileChooser = new JFileChooser();
21       fileChooser.setFileSelectionMode(
22          JFileChooser.FILES_ONLY );
23
24       int result = fileChooser.showSaveDialog( null );
```

Fig. 16.12 Creating a random-access file sequentially (part 1 of 3).

```
25
26          // if user clicked Cancel button on dialog, return
27          if ( result == JFileChooser.CANCEL_OPTION )
28             return;
29
30          // obtain selected file
31          File fileName = fileChooser.getSelectedFile();
32
33          // display error if file name invalid
34          if ( fileName == null ||
35               fileName.getName().equals( "" ) )
36             JOptionPane.showMessageDialog( null,
37                "Invalid File Name", "Invalid File Name",
38                JOptionPane.ERROR_MESSAGE );
39
40          else {
41
42             // open file
43             try {
44                RandomAccessFile file =
45                   new RandomAccessFile( fileName, "rw" );
46
47                RandomAccessAccountRecord blankRecord =
48                   new RandomAccessAccountRecord();
49
50                // write 100 blank records
51                for ( int count = 0; count < 100; count++ )
52                   blankRecord.write( file );
53
54                // close file
55                file.close();
56
57                // display message that file was created
58                JOptionPane.showMessageDialog( null,
59                   "Created file " + fileName, "Status",
60                   JOptionPane.INFORMATION_MESSAGE );
61
62                System.exit( 0 );  // terminate program
63             }
64
65             // process exceptions during open, write or
66             // close file operations
67             catch ( IOException ioException ) {
68                JOptionPane.showMessageDialog( null,
69                   "Error processing file", "Error processing file",
70                   JOptionPane.ERROR_MESSAGE );
71
72                System.exit( 1 );
73             }
74          }
75
76       }  // end method openFile
77
```

Fig. 16.12 Creating a random-access file sequentially (part 2 of 3).

```
78      // execute application to create file user specifies
79      public static void main( String args[] )
80      {
81         CreateRandomFile application = new CreateRandomFile();
82
83         application.createFile();
84      }
85
86   }  // end class CreateRandomFile
```

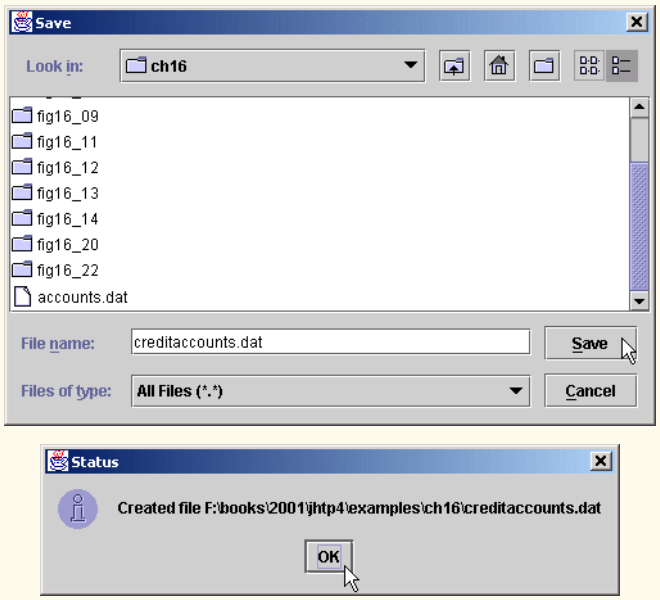


Fig. 16.12 Creating a random-access file sequentially (part 3 of 3).

Lines 44–45 attempt to open a **RandomAccessFile** for use in this program. The **RandomAccessFile** constructor receives two arguments—the file name and the *file open mode*. The file open mode for a **RandomAccessFile** is either **"r"** to open the file for reading or **"rw"** to open the file for reading and writing.

If an **IOException** occurs during the open process, the program displays a message dialog and terminates. If the file opens properly, the program uses a **for** structure (lines 51–52) to invoke **RandomAccessAccountRecord** method **write** 100 times. This statement causes the data members of object **blankRecord** to be written to the file associated with **RandomAccessFile** object **file**.

16.9 Writing Data Randomly to a Random-Access File

Figure 16.13 writes data to a file that is opened with the **"rw"** mode for reading and writing. It uses the **RandomAccessFile** method **seek** to determine the exact location in the file at which a record of information is stored. Method **seek** sets the file-position pointer to a specific position in the file relative to the beginning of the file, and the **RandomAccessAccountRecord** class method **write** outputs the data. This program assumes

the user does not enter duplicate account numbers and that the user enters appropriate data in each **`JTextField`**.

```
1  // Fig. 16.13: WriteRandomFile.java
2  // This program uses textfields to get information from the
3  // user at the keyboard and writes the information to a
4  // random-access file.
5
6  // Java core packages
7  import java.awt.*;
8  import java.awt.event.*;
9  import java.io.*;
10
11 // Java extension packages
12 import javax.swing.*;
13
14 // Deitel packages
15 import com.deitel.jhtp4.ch16.*;
16
17 public class WriteRandomFile extends JFrame {
18    private RandomAccessFile output;
19    private BankUI userInterface;
20    private JButton enterButton, openButton;
21
22    // set up GUI
23    public WriteRandomFile()
24    {
25       super( "Write to random access file" );
26
27       // create instance of reusable user interface BankUI
28       userInterface = new BankUI( 4 );  // four textfields
29       getContentPane().add( userInterface,
30          BorderLayout.CENTER );
31
32       // get reference to generic task button doTask1 in BankUI
33       openButton = userInterface.getDoTask1Button();
34       openButton.setText( "Open..." );
35
36       // register listener to call openFile when button pressed
37       openButton.addActionListener(
38
39          // anonymous inner class to handle openButton event
40          new ActionListener() {
41
42             // allow user to select file to open
43             public void actionPerformed( ActionEvent event )
44             {
45                openFile();
46             }
47
48          }  // end anonymous inner class
49
50       ); // end call to addActionListener
```

Fig. 16.13 Writing data randomly to a random-access file (part 1 of 5).

```
51
52          // register window listener for window closing event
53          addWindowListener(
54
55             // anonymous inner class to handle windowClosing event
56             new WindowAdapter() {
57
58                // add record in GUI, then close file
59                public void windowClosing( WindowEvent event )
60                {
61                   if ( output != null )
62                      addRecord();
63
64                   closeFile();
65                }
66
67             }  // end anonymous inner class
68
69          ); // end call to addWindowListener
70
71          // get reference to generic task button doTask2 in BankUI
72          enterButton = userInterface.getDoTask2Button();
73          enterButton.setText( "Enter" );
74          enterButton.setEnabled( false );
75
76          // register listener to call addRecord when button pressed
77          enterButton.addActionListener(
78
79             // anonymous inner class to handle enterButton event
80             new ActionListener() {
81
82                // add record to file
83                public void actionPerformed( ActionEvent event )
84                {
85                   addRecord();
86                }
87
88             }  // end anonymous inner class
89
90          ); // end call to addActionListener
91
92          setSize( 300, 150 );
93          show();
94       }
95
96       // enable user to choose file to open
97       private void openFile()
98       {
99          // display file dialog so user can select file
100         JFileChooser fileChooser = new JFileChooser();
101         fileChooser.setFileSelectionMode(
102            JFileChooser.FILES_ONLY );
103
```

Fig. 16.13 Writing data randomly to a random-access file (part 2 of 5).

```
104         int result = fileChooser.showOpenDialog( this );
105
106         // if user clicked Cancel button on dialog, return
107         if ( result == JFileChooser.CANCEL_OPTION )
108            return;
109
110         // obtain selected file
111         File fileName = fileChooser.getSelectedFile();
112
113         // display error if file name invalid
114         if ( fileName == null ||
115              fileName.getName().equals( "" ) )
116            JOptionPane.showMessageDialog( this,
117               "Invalid File Name", "Invalid File Name",
118               JOptionPane.ERROR_MESSAGE );
119
120         else {
121
122            // open file
123            try {
124               output = new RandomAccessFile( fileName, "rw" );
125               enterButton.setEnabled( true );
126               openButton.setEnabled( false );
127            }
128
129            // process exception while opening file
130            catch ( IOException ioException ) {
131               JOptionPane.showMessageDialog( this,
132                  "File does not exist",
133                  "Invalid File Name",
134                  JOptionPane.ERROR_MESSAGE );
135            }
136         }
137
138      }  // end method openFile
139
140      // close file and terminate application
141      private void closeFile()
142      {
143         // close file and exit
144         try {
145            if ( output != null )
146               output.close();
147
148            System.exit( 0 );
149         }
150
151         // process exception while closing file
152         catch( IOException ioException ) {
153            JOptionPane.showMessageDialog( this,
154               "Error closing file",
155               "Error", JOptionPane.ERROR_MESSAGE );
156
```

Fig. 16.13 Writing data randomly to a random-access file (part 3 of 5).

```
157            System.exit( 1 );
158         }
159      }
160
161      // add one record to file
162      public void addRecord()
163      {
164         int accountNumber = 0;
165         String fields[] = userInterface.getFieldValues();
166         RandomAccessAccountRecord record =
167            new RandomAccessAccountRecord();
168
169         // ensure account field has a value
170         if ( ! fields[ BankUI.ACCOUNT ].equals( "" ) ) {
171
172            // output values to file
173            try {
174               accountNumber =
175                  Integer.parseInt( fields[ BankUI.ACCOUNT ] );
176
177               if ( accountNumber > 0 && accountNumber <= 100 ) {
178                  record.setAccount( accountNumber );
179
180                  record.setFirstName( fields[ BankUI.FIRSTNAME ] );
181                  record.setLastName( fields[ BankUI.LASTNAME ] );
182                  record.setBalance( Double.parseDouble(
183                     fields[ BankUI.BALANCE ] ) );
184
185                  output.seek( ( accountNumber - 1 ) *
186                      RandomAccessAccountRecord.size() );
187                  record.write( output );
188               }
189
190               userInterface.clearFields();  // clear TextFields
191            }
192
193            // process improper account number or balance format
194            catch ( NumberFormatException formatException ) {
195                   JOptionPane.showMessageDialog( this,
196                      "Bad account number or balance",
197                      "Invalid Number Format",
198                      JOptionPane.ERROR_MESSAGE );
199            }
200
201            // process exceptions while writing to file
202            catch ( IOException ioException ) {
203               closeFile();
204            }
205         }
206
207      }  // end method addRecord
208
```

Fig. 16.13 Writing data randomly to a random-access file (part 4 of 5).

```
209     // execute application
210     public static void main( String args[] )
211     {
212        new WriteRandomFile();
213     }
214
215  }  // end class WriteRandomFile
```

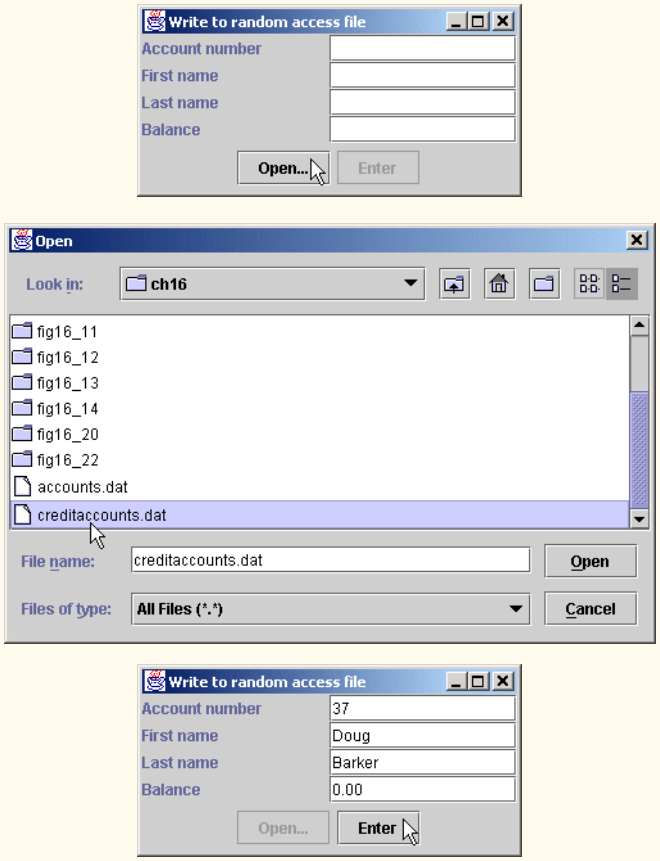


Fig. 16.13 Writing data randomly to a random-access file (part 5 of 5).

The user enters values for the account number, first name, last name and balance. When the user clicks the **Enter** button, the program calls method **`addRecord`** (162–207) of class **`WriteRandomFile`** to retrieve the data from the **`BankAccountUI`**'s **`JTextField`**s, store the data in **`RandomAccessAccountRecord`** class object **`record`** and call the **`write`** method of class **`RandomAccessAccountRecord`** to output the data.

Lines 185–186 call **`RandomAccessFile`** method ***`seek`*** to position the file-position pointer for object **`output`** to the byte location calculated by **`( accountNumber - 1 ) * RandomAccessAccountRecord.size()`**. Account numbers in this program should be between 1 and 100. We subtract 1 from the account number when calculating the byte location of the record. Thus, for record 1, the file-position pointer is set to byte 0 of the file.

When the user closes the window, the program attempts to add the last record to the file (if there is one in the GUI waiting to be output), closes the file and terminates.

16.10 Reading Data Sequentially from a Random-Access File

In the previous sections, we created a random-access file and wrote data to that file. In this section, we develop a program (Fig. 16.14) that opens a **`RandomAccessFile`** for reading with the **`"r"`** file open mode, reads through the file sequentially and displays only those records containing data. This program produces an additional benefit. See whether you can determine what it is; we will reveal it at the end of this section.

Good Programming Practice 16.1

*Open a file with the **`"r"`** file open mode for input if the contents of the file should not be modified. This prevents unintentional modification of the file's contents. This is another example of the principle of least privilege.*

```
1  // Fig. 16.14: ReadRandomFile.java
2  // This program reads a random-access file sequentially and
3  // displays the contents one record at a time in text fields.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.io.*;
9  import java.text.DecimalFormat;
10
11 // Java extension packages
12 import javax.swing.*;
13
14 // Deitel packages
15 import com.deitel.jhtp4.ch16.*;
16
17 public class ReadRandomFile extends JFrame {
18    private BankUI userInterface;
19    private RandomAccessFile input;
20    private JButton nextButton, openButton;
21
22    // set up GUI
23    public ReadRandomFile()
24    {
25       super( "Read Client File" );
26
27       // create reusable user interface instance
28       userInterface = new BankUI( 4 );  // four textfields
29       getContentPane().add( userInterface );
30
31       // configure generic doTask1 button from BankUI
32       openButton = userInterface.getDoTask1Button();
33       openButton.setText( "Open File for Reading..." );
34
```

Fig. 16.14 Reading a random-access file sequentially (part 1 of 5).

```
35         // register listener to call openFile when button pressed
36         openButton.addActionListener(
37
38            // anonymous inner class to handle openButton event
39            new ActionListener() {
40
41               // enable user to select file to open
42               public void actionPerformed( ActionEvent event )
43               {
44                  openFile();
45               }
46
47            }  // end anonymous inner class
48
49         ); // end call to addActionListener
50
51         // configure generic doTask2 button from BankUI
52         nextButton = userInterface.getDoTask2Button();
53         nextButton.setText( "Next" );
54         nextButton.setEnabled( false );
55
56         // register listener to call readRecord when button pressed
57         nextButton.addActionListener(
58
59            // anonymous inner class to handle nextButton event
60            new ActionListener() {
61
62               // read a record when user clicks nextButton
63               public void actionPerformed( ActionEvent event )
64               {
65                  readRecord();
66               }
67
68            }  // end anonymous inner class
69
70         ); // end call to addActionListener
71
72         // register listener for window closing event
73         addWindowListener(
74
75            // anonymous inner class to handle windowClosing event
76            new WindowAdapter() {
77
78               // close file and terminate application
79               public void windowClosing( WindowEvent event )
80               {
81                  closeFile();
82               }
83
84            }  // end anonymous inner class
85
86         ); // end call to addWindowListener
87
```

Fig. 16.14 Reading a random-access file sequentially (part 2 of 5).

```
88          setSize( 300, 150 );
89          show();
90       }
91
92       // enable user to select file to open
93       private void openFile()
94       {
95          // display file dialog so user can select file
96          JFileChooser fileChooser = new JFileChooser();
97          fileChooser.setFileSelectionMode(
98             JFileChooser.FILES_ONLY );
99
100         int result = fileChooser.showOpenDialog( this );
101
102         // if user clicked Cancel button on dialog, return
103         if ( result == JFileChooser.CANCEL_OPTION )
104            return;
105
106         // obtain selected file
107         File fileName = fileChooser.getSelectedFile();
108
109         // display error is file name invalid
110         if ( fileName == null ||
111              fileName.getName().equals( "" ) )
112            JOptionPane.showMessageDialog( this,
113               "Invalid File Name", "Invalid File Name",
114               JOptionPane.ERROR_MESSAGE );
115
116         else {
117
118            // open file
119            try {
120               input = new RandomAccessFile( fileName, "r" );
121               nextButton.setEnabled( true );
122               openButton.setEnabled( false );
123            }
124
125            // catch exception while opening file
126            catch ( IOException ioException ) {
127               JOptionPane.showMessageDialog( this,
128                  "File does not exist", "Invalid File Name",
129                  JOptionPane.ERROR_MESSAGE );
130            }
131         }
132
133      }  // end method openFile
134
135      // read one record
136      public void readRecord()
137      {
138         DecimalFormat twoDigits = new DecimalFormat( "0.00" );
139         RandomAccessAccountRecord record =
140            new RandomAccessAccountRecord();
```

Fig. 16.14 Reading a random-access file sequentially (part 3 of 5).

```
141
142         // read a record and display
143         try {
144
145            do {
146               record.read( input );
147            } while ( record.getAccount() == 0 );
148
149            String values[] = {
150               String.valueOf( record.getAccount() ),
151               record.getFirstName(),
152               record.getLastName(),
153               String.valueOf( record.getBalance() ) };
154            userInterface.setFieldValues( values );
155         }
156
157         // close file when end-of-file reached
158         catch ( EOFException eofException ) {
159            JOptionPane.showMessageDialog( this, "No more records",
160               "End-of-file reached",
161               JOptionPane.INFORMATION_MESSAGE );
162            closeFile();
163         }
164
165         // process exceptions from problem with file
166         catch ( IOException ioException ) {
167            JOptionPane.showMessageDialog( this,
168               "Error Reading File", "Error",
169               JOptionPane.ERROR_MESSAGE );
170
171            System.exit( 1 );
172         }
173
174      }  // end method readRecord
175
176      // close file and terminate application
177      private void closeFile()
178      {
179         // close file and exit
180         try {
181            if ( input != null )
182               input.close();
183
184            System.exit( 0 );
185         }
186
187         // process exception closing file
188         catch( IOException ioException ) {
189            JOptionPane.showMessageDialog( this,
190               "Error closing file",
191               "Error", JOptionPane.ERROR_MESSAGE );
192
193            System.exit( 1 );
```

Fig. 16.14 Reading a random-access file sequentially (part 4 of 5).

```
194         }
195      }
196
197      // execute application
198      public static void main( String args[] )
199      {
200         new ReadRandomFile();
201      }
202
203   }  // end class ReadRandomFile
```

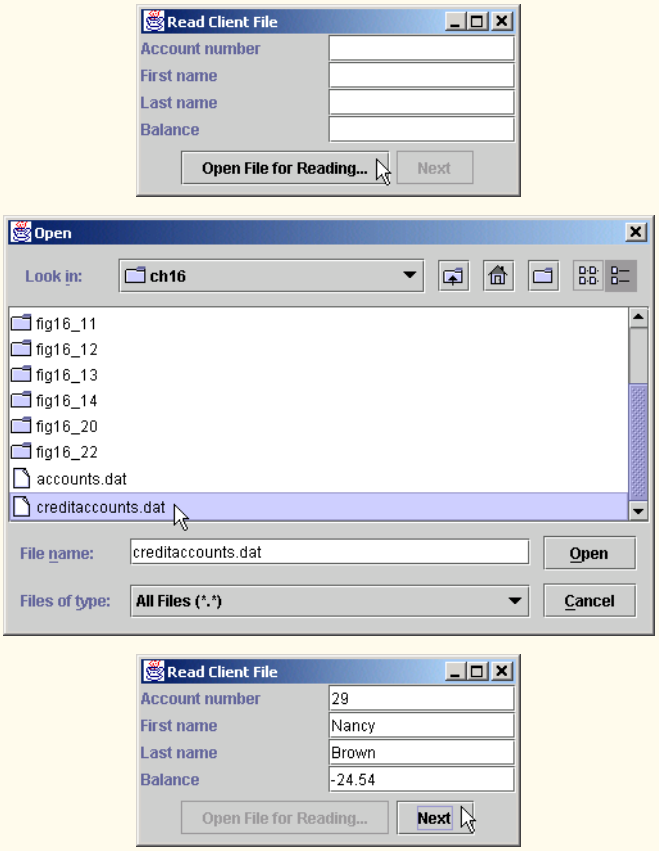


Fig. 16.14 Reading a random-access file sequentially (part 5 of 5).

When the user clicks the **Next** button to read the next record in the file, the program invokes class **`ReadRandomFile`**'s **`readRecord`** method (lines 136–174). This method invokes class **`RandomAccessAccountRecord`**'s **`read`** method (line 146) to read the data into **`RandomAccessAccountRecord`** class object **`record`**. Method **`readRecord`** reads from the file until it encounters a record with a nonzero account number (zero is the initial value for the account). When **`readRecord`** encounters a valid account number (i.e., a nonzero value), the loop terminates, and **`readRecord`** displays the record data in the text fields. When the user clicks the **Done** button or when the end-of-file

marker is encountered while reading, method **closeFile** is invoked to close the file and terminate the program.

What about that additional benefit we promised? If you examine the GUI as the program executes, you will notice that the records are displayed in sorted order (by account number)! This is a simple consequence of the way we stored these records in the file, using direct-access techniques. Compared to the bubble sort we have seen (Chapter 7), sorting with direct-access techniques is blazingly fast. The speed is achieved by making the file large enough to hold every possible record that might be created, which enables the program to insert a record between other records without having to reorganize the file. This, of course, means that the file could be sparsely occupied most of the time, a waste of storage. So this is another example of the space/time trade-off. By using large amounts of space, we are able to develop a much faster sorting algorithm.

16.11 Example: A Transaction-Processing Program

We now present a substantial transaction-processing program (Fig. 16.20), using a random-access file to achieve "instant" access processing. The program maintains a bank's account information. The program updates existing accounts, adds new accounts and deletes accounts. We assume that the program of Fig. 16.12 has been executed to create a file and that the program of Fig. 16.13 has been executed to insert initial data. The techniques used in this example have been presented in the earlier **RandomAccessFile** examples.

This program GUI consists of a window with a menu bar containing a **File** menu and internal frames that enable the user to perform insert, update and delete record operations on the file. The internal frames are subclasses of **JInternalFrame** that are managed by a **JDesktopPane** (as discussed in Chapter 13). The **File** menu has five menu items to select various tasks, as shown in Fig. 16.15.

When the user selects **Update Record** from the **File** menu, the **Update Record** internal frame (Fig. 16.16) allows the user to update an existing account. The code that implements the **Update Record** internal frame is in class **UpdateDialog** (lines 238–458 of Fig. 16.20). In the first screen capture of Fig. 16.16, the user inputs an account number and presses *Enter* to invoke the account textfield's **actionPerformed** method (lines 345–360 of Fig. 16.20). This reads the account from the file with method **getRecord** (lines 371–418 of Fig. 16.20), which validates the account number, then reads the record with **RandomAccessAccountRecord** method **read**. Next, **getRecord** compares the account number with zero (i.e., no record) to determine whether the record contains information. If not, **getRecord** displays a message stating that the record does not exist; otherwise, it returns the record. Lines 350–357 of the account textfield's **actionPerformed** method extract the account information from the record and display the account information in the internal frame (as shown in the second screen capture of Fig. 16.16). The **Transaction amount** textfield initially contains the string **charge (+) or payment (–)**. The user should select this text and type the transaction amount (a positive value for a charge or a negative value for a payment), then press *Enter* to invoke the transaction textfield's **actionPerformed** method (lines 295–330 of Fig. 16.20). Method **addRecord** (lines 421–456 of Fig. 16.20) takes the transaction amount, adds it to the current balance and calls **RandomAccessAccountRecord** method **setBalance** to update the display. Clicking **Save Changes** writes the updated record to disk; clicking **Cancel** closes the internal frame without writing the record to disk. The windows in Fig. 16.17 show a sample of a transaction being input.

When the user selects **New Record** from the **File** menu, the **New Record** internal frame in Fig. 16.18 allows the user to add a new record. The code that implements the **New Record** internal frame is in class **`NewDialog`** (lines 461–615 of Fig. 16.20). The user enters data in the **`JTextField`**s and clicks **Save Changes** to write the record to disk. If the account number already exists, the program displays an error message and does not attempt to write the record. Clicking **Cancel** closes the internal frame without attempting to write the record.

Selecting **Delete Record** from the **File** menu displays the **Delete Record** internal frame in Fig. 16.19, which allows the user to delete a record from the file. The code that implements the **Delete Record** internal frame is in class **`DeleteDialog`** (lines 618–774 of Fig. 16.20). The user enters the account number in the **`JTextField`** and presses *Enter*. Only an existing record can be deleted, so, if the specified account is empty, the program displays an error message. This enables the user to check whether the record exists before deleting the record. Clicking the **Delete Record** button in the internal frame sets the record's account number to 0 (which this application considers to be an empty record). Clicking **Cancel** closes the internal frame without deleting the record.

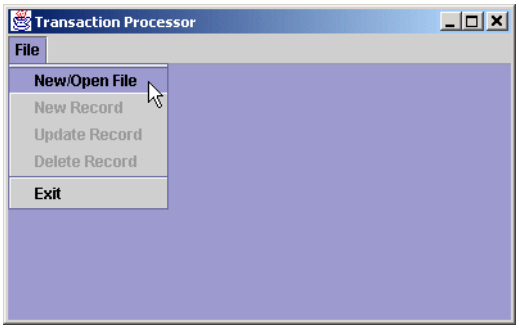


Fig. 16.15 The initial **Transaction Processor** window.

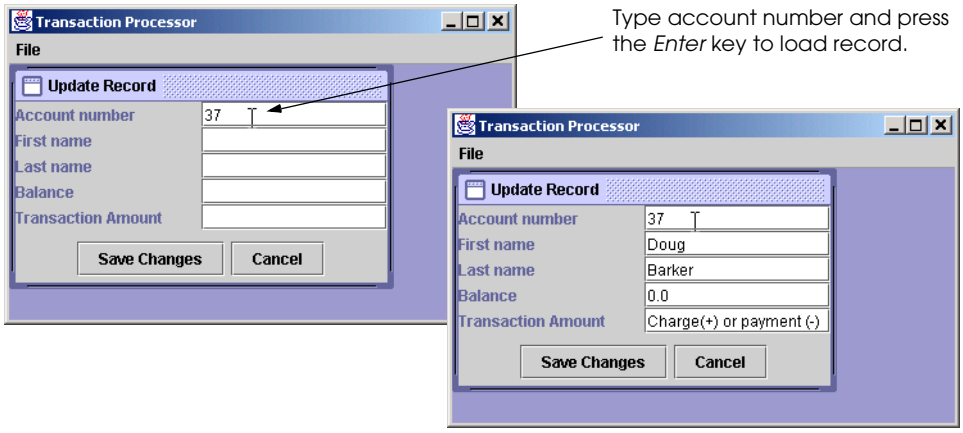


Fig. 16.16 Loading a record into the **Update Record** internal frame.

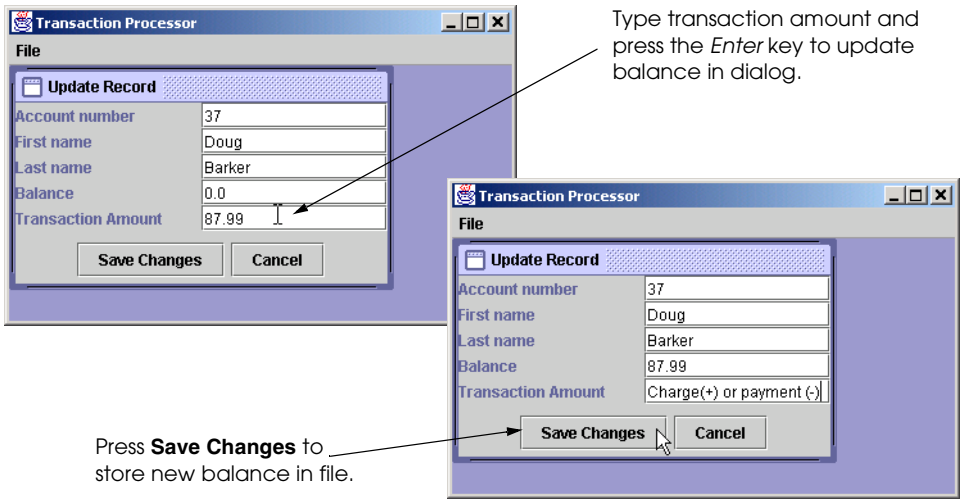


Fig. 16.17 Inputting a transaction in the **Update Record** internal frame.

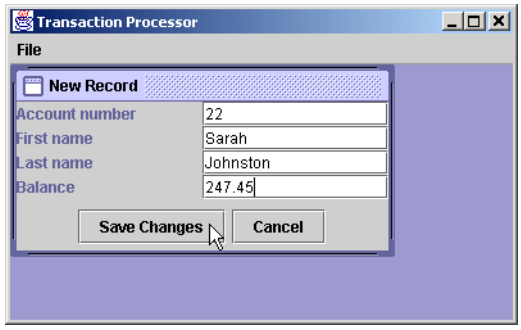


Fig. 16.18 **New Record** internal frame.

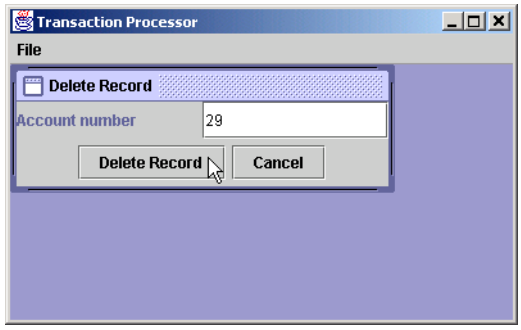


Fig. 16.19 **Delete Record** internal frame.

The **TransactionProcessor** program appears in Fig. 16.20. The program opens the file with file open mode **"rw"** (reading and writing).

```
1  // Transaction processing program using RandomAccessFiles.
2  // This program reads a random-access file sequentially,
3  // updates records already written to the file, creates new
4  // records to be placed in the file and deletes data
5  // already in the file.
6
7  // Java core packages
8  import java.awt.*;
9  import java.awt.event.*;
10 import java.io.*;
11 import java.text.DecimalFormat;
12
13 // Java extension packages
14 import javax.swing.*;
15
16 // Deitel packages
17 import com.deitel.jhtp4.ch16.*;
18
19 public class TransactionProcessor extends JFrame {
20    private UpdateDialog updateDialog;
21    private NewDialog newDialog;
22    private DeleteDialog deleteDialog;
23    private JMenuItem newItem, updateItem, deleteItem,
24       openItem, exitItem;
25    private JDesktopPane desktop;
26    private RandomAccessFile file;
27    private RandomAccessAccountRecord record;
28
29    // set up GUI
30    public TransactionProcessor()
31    {
32       super( "Transaction Processor" );
33
34       // set up desktop, menu bar and File menu
35       desktop = new JDesktopPane();
36       getContentPane().add( desktop );
37
38       JMenuBar menuBar = new JMenuBar();
39       setJMenuBar( menuBar );
40
41       JMenu fileMenu = new JMenu( "File" );
42       menuBar.add( fileMenu );
43
44       // set up menu item for adding a record
45       newItem = new JMenuItem( "New Record" );
46       newItem.setEnabled( false );
47
```

Fig. 16.20 Transaction-processing program (part 1 of 15).

```
48          // display new record dialog when user selects New Record
49          newItem.addActionListener(
50
51             new ActionListener() {
52
53                public void actionPerformed( ActionEvent event )
54                {
55                   newDialog.setVisible( true );
56                }
57             }
58          );
59
60          // set up menu item for updating a record
61          updateItem = new JMenuItem( "Update Record" );
62          updateItem.setEnabled( false );
63
64          // display update dialog when user selects Update Record
65          updateItem.addActionListener(
66
67             new ActionListener() {
68
69                public void actionPerformed( ActionEvent event )
70                {
71                   updateDialog.setVisible( true );
72                }
73             }
74          );
75
76          // set up menu item for deleting a record
77          deleteItem = new JMenuItem( "Delete Record" );
78          deleteItem.setEnabled( false );
79
80          // display delete dialog when user selects Delete Record
81          deleteItem.addActionListener(
82
83             new ActionListener() {
84
85                public void actionPerformed( ActionEvent event )
86                {
87                   deleteDialog.setVisible( true );
88                }
89             }
90          );
91
92          // set up button for opening file
93          openItem = new JMenuItem( "New/Open File" );
94
95          // enable user to select file to open, then set up
96          // dialog boxes
97          openItem.addActionListener(
98
99             new ActionListener() {
100
```

Fig. 16.20 Transaction-processing program (part 2 of 15).

```
101             public void actionPerformed( ActionEvent event )
102             {
103                boolean opened = openFile();
104
105                if ( !opened )
106                   return;
107
108                openItem.setEnabled( false );
109
110                // set up internal frames for record processing
111                updateDialog = new UpdateDialog( file );
112                desktop.add( updateDialog );
113
114                deleteDialog = new DeleteDialog( file );
115                desktop.add ( deleteDialog );
116
117                newDialog = new NewDialog( file );
118                desktop.add( newDialog );
119             }
120
121          }  // end anonymous inner class
122
123       ); // end call to addActionListener
124
125       // set up menu item for exiting program
126       exitItem = new JMenuItem( "Exit" );
127       exitItem.setEnabled( true );
128
129       // teminate application
130       exitItem.addActionListener(
131
132          new ActionListener() {
133
134             public void actionPerformed( ActionEvent event )
135             {
136                closeFile();
137             }
138          }
139       );
140
141       // attach menu items to File menu
142       fileMenu.add( openItem );
143       fileMenu.add( newItem );
144       fileMenu.add( updateItem );
145       fileMenu.add( deleteItem );
146       fileMenu.addSeparator();
147       fileMenu.add( exitItem );
148
149       // configure window
150       setDefaultCloseOperation(
151          WindowConstants.DO_NOTHING_ON_CLOSE );
152
153       setSize( 400, 250  );
```

Fig. 16.20 Transaction-processing program (part 3 of 15).

```
154         setVisible( true );
155
156      }  // end TransactionProcessor constructor
157
158      // enable user to select file to open
159      private boolean openFile()
160      {
161         // display dialog so user can select file
162         JFileChooser fileChooser = new JFileChooser();
163         fileChooser.setFileSelectionMode(
164            JFileChooser.FILES_ONLY );
165
166         int result = fileChooser.showOpenDialog( this );
167
168         // if user clicked Cancel button on dialog, return
169         if ( result == JFileChooser.CANCEL_OPTION )
170            return false;
171
172         // obtain selected file
173         File fileName = fileChooser.getSelectedFile();
174
175         // display error if file name invalid
176         if ( fileName == null ||
177              fileName.getName().equals( "" ) ) {
178            JOptionPane.showMessageDialog( this,
179               "Invalid File Name", "Invalid File Name",
180               JOptionPane.ERROR_MESSAGE );
181
182            return false;
183         }
184
185         else {
186
187            // open file
188            try {
189               file = new RandomAccessFile( fileName, "rw" );
190               openItem.setEnabled( false );
191               newItem.setEnabled( true );
192               updateItem.setEnabled( true );
193               deleteItem.setEnabled( true );
194            }
195
196            // process problems opening file
197            catch ( IOException ioException ) {
198               JOptionPane.showMessageDialog( this,
199                  "File does not exist", "Invalid File Name",
200                  JOptionPane.ERROR_MESSAGE );
201
202               return false;
203            }
204         }
205
206         return true;  // file opened
```

Fig. 16.20 Transaction-processing program (part 4 of 15).

```
207     }
208
209     // close file and terminate application
210     private void closeFile()
211     {
212        // close file and exit
213        try {
214           if ( file != null )
215              file.close();
216
217           System.exit( 0 );
218        }
219
220        // process exceptions closing file
221        catch( IOException ioException ) {
222           JOptionPane.showMessageDialog( this,
223              "Error closing file",
224              "Error", JOptionPane.ERROR_MESSAGE );
225           System.exit( 1 );
226        }
227     }
228
229     // execute application
230     public static void main( String args[] )
231     {
232        new TransactionProcessor();
233     }
234
235  }  // end class TransactionProcessor
236
237  // class for udpating records
238  class UpdateDialog extends JInternalFrame {
239     private RandomAccessFile file;
240     private BankUI userInterface;
241
242     // set up GUI
243     public UpdateDialog( RandomAccessFile updateFile )
244     {
245        super( "Update Record" );
246
247        file = updateFile;
248
249        // set up GUI components
250        userInterface = new BankUI( 5 );
251        getContentPane().add( userInterface,
252           BorderLayout.CENTER );
253
254        // set up Save Changes button and register listener
255        JButton saveButton = userInterface.getDoTask1Button();
256        saveButton.setText( "Save Changes" );
257
258        saveButton.addActionListener(
259
```

Fig. 16.20 Transaction-processing program (part 5 of 15).

```
260            new ActionListener() {
261
262               public void actionPerformed( ActionEvent event )
263               {
264                  addRecord( getRecord() );
265                  setVisible( false );
266                  userInterface.clearFields();
267               }
268            }
269         );
270
271         // set up Cancel button and register listener
272         JButton cancelButton = userInterface.getDoTask2Button();
273         cancelButton.setText( "Cancel" );
274
275         cancelButton.addActionListener(
276
277            new ActionListener() {
278
279               public void actionPerformed( ActionEvent event )
280               {
281                  setVisible( false );
282                  userInterface.clearFields();
283               }
284            }
285         );
286
287         // set up listener for transaction textfield
288         JTextField transactionField =
289            userInterface.getFields()[ BankUI.TRANSACTION ];
290
291         transactionField.addActionListener(
292
293            new ActionListener() {
294
295               public void actionPerformed( ActionEvent event )
296               {
297                  // add transaction amount to balance
298                  try {
299                     RandomAccessAccountRecord record = getRecord();
300
301                     // get textfield values from userInterface
302                     String fieldValues[] =
303                        userInterface.getFieldValues();
304
305                     // get transaction amount
306                     double change = Double.parseDouble(
307                        fieldValues[ BankUI.TRANSACTION ] );
308
309                     // specify Strings to display in GUI
310                     String[] values = {
311                        String.valueOf( record.getAccount() ),
312                        record.getFirstName(),
```

Fig. 16.20 Transaction-processing program (part 6 of 15).

```
313                      record.getLastName(),
314                      String.valueOf( record.getBalance()
315                         + change ),
316                      "Charge(+) or payment (-)" };
317
318                   // display Strings in GUI
319                   userInterface.setFieldValues( values );
320                }
321
322                // process invalid number in transaction field
323                catch ( NumberFormatException numberFormat ) {
324                   JOptionPane.showMessageDialog( null,
325                      "Invalid Transaction",
326                      "Invalid Number Format",
327                      JOptionPane.ERROR_MESSAGE );
328                }
329
330             }  // end method actionPerformed
331
332          }  // end anonymous inner class
333
334       ); // end call to addActionListener
335
336       // set up listener for account text field
337       JTextField accountField =
338          userInterface.getFields()[ BankUI.ACCOUNT ];
339
340       accountField.addActionListener(
341
342          new ActionListener() {
343
344             // get record and display contents in GUI
345             public void actionPerformed( ActionEvent event )
346             {
347                RandomAccessAccountRecord record = getRecord();
348
349                if ( record.getAccount() != 0 )  {
350                   String values[] = {
351                      String.valueOf( record.getAccount() ),
352                      record.getFirstName(),
353                      record.getLastName(),
354                      String.valueOf( record.getBalance() ),
355                      "Charge(+) or payment (-)" };
356
357                   userInterface.setFieldValues( values );
358                }
359
360             }  // end method actionPerformed
361
362          }  // end anonymous inner class
363
364       ); // end call to addActionListener
365
```

Fig. 16.20 Transaction-processing program (part 7 of 15).

```
366         setSize( 300, 175 );
367         setVisible( false );
368      }
369
370      // get record from file
371      private RandomAccessAccountRecord getRecord()
372      {
373         RandomAccessAccountRecord record =
374            new RandomAccessAccountRecord();
375
376         // get record from file
377         try {
378            JTextField accountField =
379               userInterface.getFields()[ BankUI.ACCOUNT ];
380
381            int accountNumber =
382               Integer.parseInt( accountField.getText() );
383
384            if ( accountNumber < 1 || accountNumber > 100 ) {
385               JOptionPane.showMessageDialog( this,
386                  "Account Does Not Exist",
387                  "Error", JOptionPane.ERROR_MESSAGE );
388               return record;
389            }
390
391            // seek to appropriate record location in file
392            file.seek( ( accountNumber - 1 ) *
393               RandomAccessAccountRecord.size() );
394            record.read( file );
395
396            if ( record.getAccount() == 0 )
397               JOptionPane.showMessageDialog( this,
398                  "Account Does Not Exist",
399                  "Error", JOptionPane.ERROR_MESSAGE );
400         }
401
402         // process invalid account number format
403         catch ( NumberFormatException numberFormat ) {
404            JOptionPane.showMessageDialog( this,
405               "Invalid Account", "Invalid Number Format",
406               JOptionPane.ERROR_MESSAGE );
407         }
408
409         // process file processing problems
410         catch ( IOException ioException ) {
411            JOptionPane.showMessageDialog( this,
412               "Error Reading File",
413               "Error", JOptionPane.ERROR_MESSAGE );
414         }
415
416         return record;
417
418      }  // end method getRecord
```

Fig. 16.20 Transaction-processing program (part 8 of 15).

```
419
420    // add record to file
421    public void addRecord( RandomAccessAccountRecord record )
422    {
423       // update record in file
424       try {
425          int accountNumber = record.getAccount();
426
427          file.seek( ( accountNumber - 1 ) *
428             RandomAccessAccountRecord.size() );
429
430          String[] values = userInterface.getFieldValues();
431
432          // set firstName, lastName and balance in record
433          record.setFirstName( values[ BankUI.FIRSTNAME ] );
434          record.setLastName( values[ BankUI.LASTNAME ] );
435          record.setBalance(
436             Double.parseDouble( values[ BankUI.BALANCE ]  ) );
437
438          // rewrite record to file
439          record.write( file );
440       }
441
442       // process file processing problems
443       catch ( IOException ioException ) {
444          JOptionPane.showMessageDialog( this,
445             "Error Writing To File",
446             "Error", JOptionPane.ERROR_MESSAGE );
447       }
448
449       // process invalid balance value
450       catch ( NumberFormatException numberFormat ) {
451          JOptionPane.showMessageDialog( this,
452          "Bad Balance", "Invalid Number Format",
453          JOptionPane.ERROR_MESSAGE );
454       }
455
456    }  // end method addRecord
457
458 }  // end class UpdateDialog
459
460 // class for creating new records
461 class NewDialog extends JInternalFrame {
462    private RandomAccessFile file;
463    private BankUI userInterface;
464
465    // set up GUI
466    public NewDialog( RandomAccessFile newFile )
467    {
468       super( "New Record" );
469
470       file = newFile;
471
```

Fig. 16.20 Transaction-processing program (part 9 of 15).

```
472         // attach user interface to dialog
473         userInterface = new BankUI( 4 );
474         getContentPane().add( userInterface,
475            BorderLayout.CENTER );
476
477         // set up Save Changes button and register listener
478         JButton saveButton = userInterface.getDoTask1Button();
479         saveButton.setText( "Save Changes" );
480
481         saveButton.addActionListener(
482
483            new ActionListener() {
484
485               // add new record to file
486               public void actionPerformed( ActionEvent event )
487               {
488                  addRecord( getRecord() );
489                  setVisible( false );
490                  userInterface.clearFields();
491               }
492
493            }  // end anonymous inner class
494
495         ); // end call to addActionListener
496
497         JButton cancelButton = userInterface.getDoTask2Button();
498         cancelButton.setText( "Cancel" );
499
500         cancelButton.addActionListener(
501
502            new ActionListener() {
503
504               // dismiss dialog without storing new record
505               public void actionPerformed( ActionEvent event )
506               {
507                 setVisible( false );
508                 userInterface.clearFields();
509               }
510
511            }  // end anonymous inner class
512
513         ); // end call to addActionListener
514
515         setSize( 300, 150 );
516         setVisible( false );
517
518      }  // end constructor
519
520      // get record from file
521      private RandomAccessAccountRecord getRecord()
522      {
523         RandomAccessAccountRecord record =
524            new RandomAccessAccountRecord();
```

Fig. 16.20 Transaction-processing program (part 10 of 15).

```
525
526         // get record from file
527         try {
528            JTextField accountField =
529               userInterface.getFields()[ BankUI.ACCOUNT ];
530
531            int accountNumber =
532               Integer.parseInt( accountField.getText() );
533
534            if ( accountNumber < 1 || accountNumber > 100 ) {
535               JOptionPane.showMessageDialog( this,
536                  "Account Does Not Exist",
537                  "Error", JOptionPane.ERROR_MESSAGE );
538               return record;
539            }
540
541            // seek to record location
542            file.seek( ( accountNumber - 1 ) *
543               RandomAccessAccountRecord.size() );
544
545            // read record from file
546            record.read( file );
547         }
548
549         // process invalid account number format
550         catch ( NumberFormatException numberFormat ) {
551            JOptionPane.showMessageDialog( this,
552               "Account Does Not Exist", "Invalid Number Format",
553               JOptionPane.ERROR_MESSAGE );
554         }
555
556         // process file processing problems
557         catch ( IOException ioException ) {
558            JOptionPane.showMessageDialog( this,
559               "Error Reading File",
560               "Error", JOptionPane.ERROR_MESSAGE );
561         }
562
563         return record;
564
565      }  // end method getRecord
566
567      // add record to file
568      public void addRecord( RandomAccessAccountRecord record )
569      {
570         String[] fields = userInterface.getFieldValues();
571
572         if ( record.getAccount() != 0 ) {
573            JOptionPane.showMessageDialog( this,
574               "Record Already Exists",
575               "Error", JOptionPane.ERROR_MESSAGE );
576            return;
577         }
```

Fig. 16.20 Transaction-processing program (part 11 of 15).

```
578
579         // output the values to the file
580         try {
581
582            // set account, first name, last name and balance
583            // for record
584            record.setAccount( Integer.parseInt(
585               fields[ BankUI.ACCOUNT ] ) );
586            record.setFirstName( fields[ BankUI.FIRSTNAME ] );
587            record.setLastName( fields[ BankUI.LASTNAME ] );
588            record.setBalance( Double.parseDouble(
589               fields[ BankUI.BALANCE ] ) );
590
591            // seek to record location
592            file.seek( ( record.getAccount() - 1 ) *
593               RandomAccessAccountRecord.size() );
594
595            // write record
596            record.write( file );
597         }
598
599         // process invalid account or balance format
600         catch ( NumberFormatException numberFormat ) {
601            JOptionPane.showMessageDialog( this,
602               "Invalid Balance", "Invalid Number Format",
603               JOptionPane.ERROR_MESSAGE );
604         }
605
606         // process file processing problems
607         catch ( IOException ioException ) {
608            JOptionPane.showMessageDialog( this,
609               "Error Writing To File",
610               "Error", JOptionPane.ERROR_MESSAGE );
611         }
612
613      }  // end method addRecord
614
615   }  // end class NewDialog
616
617   // class for deleting records
618   class DeleteDialog extends JInternalFrame {
619      private RandomAccessFile file;  // file for output
620      private BankUI userInterface;
621
622      // set up GUI
623      public DeleteDialog( RandomAccessFile deleteFile )
624      {
625         super( "Delete Record" );
626
627         file = deleteFile;
628
629         // create BankUI with only account field
630         userInterface = new BankUI( 1 );
```

Fig. 16.20 Transaction-processing program (part 12 of 15).

```
631
632         getContentPane().add( userInterface,
633            BorderLayout.CENTER );
634
635         // set up Delete Record button and register listener
636         JButton deleteButton = userInterface.getDoTask1Button();
637         deleteButton.setText( "Delete Record" );
638
639         deleteButton.addActionListener(
640
641            new ActionListener() {
642
643               // overwrite existing record
644               public void actionPerformed( ActionEvent event )
645               {
646                  addRecord( getRecord() );
647                  setVisible( false );
648                  userInterface.clearFields();
649               }
650
651            }  // end anonymous inner class
652
653         ); // end call to addActionListener
654
655         // set up Cancel button and register listener
656         JButton cancelButton = userInterface.getDoTask2Button();
657         cancelButton.setText( "Cancel" );
658
659         cancelButton.addActionListener(
660
661            new ActionListener() {
662
663               // cancel delete operation by hiding dialog
664               public void actionPerformed( ActionEvent event )
665               {
666                  setVisible( false );
667               }
668
669            }  // end anonymous inner class
670
671         ); // end call to addActionListener
672
673         // set up listener for account text field
674         JTextField accountField =
675            userInterface.getFields()[ BankUI.ACCOUNT ];
676
677         accountField.addActionListener(
678
679            new ActionListener() {
680
681               public void actionPerformed( ActionEvent event )
682               {
683                  RandomAccessAccountRecord record = getRecord();
```

Fig. 16.20 Transaction-processing program (part 13 of 15).

```
684             }
685
686          }  // end anonymous inner class
687
688       ); // end call to addActionListener
689
690       setSize( 300, 100 );
691       setVisible( false );
692
693    }  // end constructor
694
695    // get record from file
696    private RandomAccessAccountRecord getRecord()
697    {
698       RandomAccessAccountRecord record =
699          new RandomAccessAccountRecord();
700
701       // get record from file
702       try {
703          JTextField accountField =
704             userInterface.getFields()[ BankUI.ACCOUNT ];
705
706          int accountNumber =
707             Integer.parseInt( accountField.getText() );
708
709          if ( accountNumber < 1 || accountNumber > 100 ) {
710             JOptionPane.showMessageDialog( this,
711                "Account Does Not Exist",
712                "Error", JOptionPane.ERROR_MESSAGE );
713             return( record );
714          }
715
716          // seek to record location and read record
717          file.seek( ( accountNumber - 1 ) *
718             RandomAccessAccountRecord.size() );
719          record.read( file );
720
721          if ( record.getAccount() == 0 )
722             JOptionPane.showMessageDialog( this,
723                "Account Does Not Exist",
724                "Error", JOptionPane.ERROR_MESSAGE );
725       }
726
727       // process invalid account number format
728       catch ( NumberFormatException numberFormat ) {
729          JOptionPane.showMessageDialog( this,
730             "Account Does Not Exist",
731             "Invalid Number Format",
732             JOptionPane.ERROR_MESSAGE );
733       }
734
735       // process file processing problems
736       catch ( IOException ioException ) {
```

Fig. 16.20 Transaction-processing program (part 14 of 15).

```
737           JOptionPane.showMessageDialog( this,
738              "Error Reading File",
739              "Error", JOptionPane.ERROR_MESSAGE );
740        }
741
742        return record;
743
744     }  // end method getRecord
745
746     // add record to file
747     public void addRecord( RandomAccessAccountRecord record )
748     {
749        if ( record.getAccount() == 0 )
750           return;
751
752        // delete record by setting account number to 0
753        try {
754           int accountNumber = record.getAccount();
755
756           // seek to record position
757           file.seek( ( accountNumber - 1 ) *
758              RandomAccessAccountRecord.size() );
759
760           // set account to 0 and overwrite record
761           record.setAccount( 0 );
762           record.write( file );
763        }
764
765        // process file processing problems
766        catch ( IOException ioException ) {
767           JOptionPane.showMessageDialog( this,
768              "Error Writing To File",
769              "Error", JOptionPane.ERROR_MESSAGE );
770        }
771
772     }  // end method addRecord
773
774  }  // end class DeleteDialog
```

Fig. 16.20 Transaction-processing program (part 15 of 15).

16.12 Class `File`

As we stated at the beginning of this chapter, the **`java.io`** package contains an abundance of classes for processing input and output. We concentrated on the classes for processing sequential files (**`FileInputStream`** and **`FileOutputStream`**), for processing object streams (**`ObjectInputStream`** and **`ObjectOutputStream`**) and for processing random-access files (**`RandomAccessFile`**). In this section, we discuss class **`File`**, which is particularly useful for retrieving information about a file or a directory from a disk. Objects of class **`File`** do not open files or provide any file-processing capabilities.

One application of a **`File`** object is to determine whether a file exists before attempting to open the file. In *Common Programming Error 16.1*, we warned that opening an existing file for output by using a **`FileOutputStream`** object discards the contents

of that file *without warning*. If a program using a **File** determines that a file already exists, the program can warn that the user is about to discard the original file's contents.

Good Programming Practice 16.2

Use a **File** *object to determine whether a file exists before opening the file with a* **FileOutputStream** *object.*

Class **File** provides three constructors. The constructor

```
public File( String name )
```

stores the **String** argument **name** in the object. The **name** can contain *path information* as well as a file or directory name. A file or directory's path specifies the location of the file or directory on disk. The path includes some or all of the directories leading to the file or directory. An *absolute path* contains all the directories, starting with the *root directory* that lead to a specific file or directory. Every file or directory on a particular disk drive has the same root directory in its path. A *relative path* contains a subset of the directories leading to a specific file or directory. Relative paths normally start from the directory in which the application began executing.

The constructor

```
public File( String pathToName, String name )
```

uses argument **pathToName** (an absolute or relative path) to locate the file or directory specified by **name**.

The constructor

```
public File( File directory, String name )
```

uses an existing **File** object **directory** (an absolute or relative path) to locate the file or directory specified by **name**.

Figure 16.21 discusses some common **File** methods. See the Java API for other **File** methods.

Method	Description
boolean canRead()	Returns **true** if a file is readable; **false** otherwise.
boolean canWrite()	Returns **true** if a file is writable; **false** otherwise.
boolean exists()	Returns **true** if the name specified as the argument to the **File** constructor is a file or directory in the specified path; **false** otherwise.
boolean isFile()	Returns **true** if the name specified as the argument to the **File** constructor is a file; **false** otherwise.
boolean isDirectory()	Returns **true** if the name specified as the argument to the **File** constructor is a directory; **false** otherwise.
boolean isAbsolute()	Returns **true** if the arguments specified to the **File** constructor indicate an absolute path to a file or directory; **false** otherwise.

Fig. 16.21 Some commonly used **File** methods (part 1 of 2).

Method	Description
`String getAbsolutePath()`	Returns a `String` with the absolute path of the file or directory.
`String getName()`	Returns a `String` with the name of the file or directory.
`String getPath()`	Returns a `String` with the path of the file or directory.
`String getParent()`	Returns a `String` with the parent directory of the file or directory—that is, the directory in which the file or directory can be found.
`long length()`	Returns the length of the file in bytes. If the `File` object represents a directory, `0` is returned.
`long lastModified()`	Returns a platform-dependent representation of the time at which the file or directory was last modified. The value returned is only useful for comparison with other values returned by this method.
`String[] list()`	Returns an array of `String`s representing the contents of a directory.

Fig. 16.21 Some commonly used `File` methods (part 2 of 2).

Good Programming Practice 16.3

Use `File` method `isFile` to determine that a `File` object represents a file (not a directory) before attempting to open a file.

Good Programming Practice 16.4

Before attempting to open a file for reading, use `File` method `canRead` to determine whether the file is readable.

Good Programming Practice 16.5

Before attempting to open a file for writing, use `File` method `canWrite` to determine whether the file is writable.

Figure 16.22 demonstrates class `File`. The `FileTest` application creates a GUI containing a `JTextField` for entering a file name or directory name and a `JTextArea` for displaying information about the file name or directory name input.

```
1  // Fig. 16.22: FileTest.java
2  // Demonstrating the File class.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.io.*;
8
```

Fig. 16.22 Demonstrating class `File` (part 1 of 4).

```
 9  // Java extension packages
10  import javax.swing.*;
11
12  public class FileTest extends JFrame
13     implements ActionListener {
14
15     private JTextField enterField;
16     private JTextArea outputArea;
17
18     // set up GUI
19     public FileTest()
20     {
21        super( "Testing class File" );
22
23        enterField = new JTextField(
24           "Enter file or directory name here" );
25        enterField.addActionListener( this );
26        outputArea = new JTextArea();
27
28        ScrollPane scrollPane = new ScrollPane();
29        scrollPane.add( outputArea );
30
31        Container container = getContentPane();
32        container.add( enterField, BorderLayout.NORTH );
33        container.add( scrollPane, BorderLayout.CENTER );
34
35        setSize( 400, 400 );
36        show();
37     }
38
39     // display information about file user specifies
40     public void actionPerformed( ActionEvent actionEvent )
41     {
42        File name = new File( actionEvent.getActionCommand() );
43
44        // if name exists, output information about it
45        if ( name.exists() ) {
46           outputArea.setText(
47              name.getName() + " exists\n" +
48              ( name.isFile() ?
49                 "is a file\n" : "is not a file\n" ) +
50              ( name.isDirectory() ?
51                 "is a directory\n" : "is not a directory\n" ) +
52              ( name.isAbsolute() ? "is absolute path\n" :
53                 "is not absolute path\n" ) +
54              "Last modified: " + name.lastModified() +
55              "\nLength: " + name.length() +
56              "\nPath: " + name.getPath() +
57              "\nAbsolute path: " + name.getAbsolutePath() +
58              "\nParent: " + name.getParent() );
59
60           // output information if name is a file
61           if ( name.isFile() ) {
```

Fig. 16.22 Demonstrating class **`File`** (part 2 of 4).

```
62
63             // append contents of file to outputArea
64             try {
65                BufferedReader input = new BufferedReader(
66                   new FileReader( name ) );
67                StringBuffer buffer = new StringBuffer();
68                String text;
69                outputArea.append( "\n\n" );
70
71                while ( ( text = input.readLine() ) != null )
72                   buffer.append( text + "\n" );
73
74                outputArea.append( buffer.toString() );
75             }
76
77             // process file processing problems
78             catch( IOException ioException ) {
79                JOptionPane.showMessageDialog( this,
80                   "FILE ERROR",
81                   "FILE ERROR", JOptionPane.ERROR_MESSAGE );
82             }
83          }
84
85          // output directory listing
86          else if ( name.isDirectory() ) {
87             String directory[] = name.list();
88
89             outputArea.append( "\n\nDirectory contents:\n");
90
91             for ( int i = 0; i < directory.length; i++ )
92                outputArea.append( directory[ i ] + "\n" );
93          }
94       }
95
96       // not file or directory, output error message
97       else {
98          JOptionPane.showMessageDialog( this,
99             actionEvent.getActionCommand() + " Does Not Exist",
100            "ERROR", JOptionPane.ERROR_MESSAGE );
101      }
102
103   }  // end method actionPerformed
104
105   // execute application
106   public static void main( String args[] )
107   {
108      FileTest application = new FileTest();
109
110      application.setDefaultCloseOperation(
111         JFrame.EXIT_ON_CLOSE );
112   }
113
114 }  // end class FileTest
```

Fig. 16.22 Demonstrating class **`File`** (part 3 of 4).

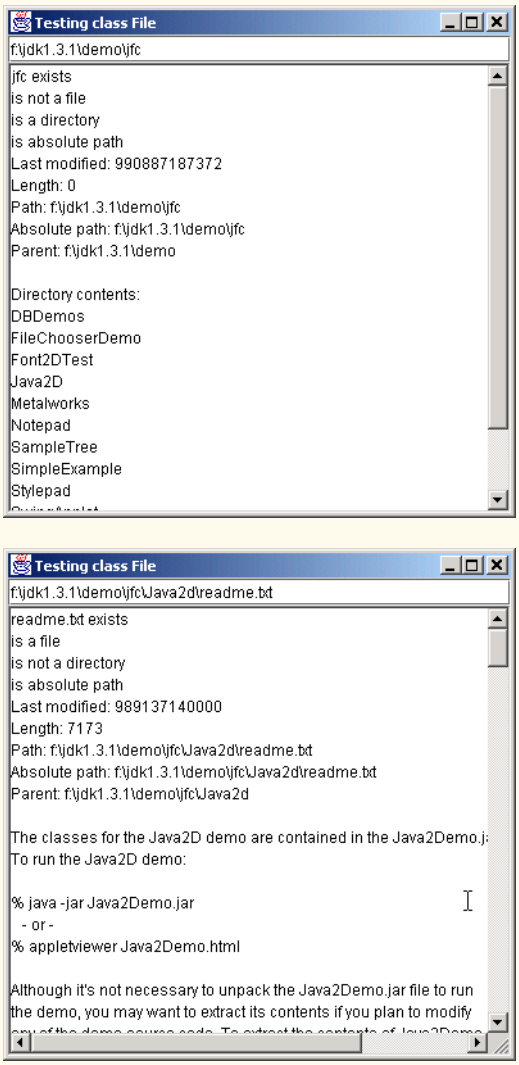


Fig. 16.22 Demonstrating class **`File`** (part 4 of 4).

The user types a file name or directory name into the text field and presses the *Enter* key to invoke method **`actionPerformed`** (lines 40–103), which creates a new **`File`** object (line 42) and assigns it to **`name`**. Line 45 invokes **`File`** method **`exists`** to determine whether the name input by the user exists (either as a file or as a directory) on the disk. If the name input by the user does not exist, the **`actionPerformed`** method proceeds to lines 97–101 and displays a message dialog containing the name the user typed, followed by "**`Does Not Exist`**." Otherwise, the body of the **`if`** structure (lines 45–94) executes. The program outputs the name of the file or directory, then outputs the results of testing the **`File`** object with **`isFile`** (line 48), **`isDirectory`** (line 50) and **`isAbsolute`** (line 52). Next, the program displays the values returned by **`lastModified`** (line 54),

length (line 55), **getPath** (line 56), **getAbsolutePath** (line 57) and **getParent** (line 58).

If the **File** object represents a file (line 61), the program reads the contents of the file and displays the contents in the **JTextArea**. The program uses a **BufferedReader** object chained to a **FileReader** object (lines 65–66) to open the file for reading and to read the file one line at a time with method **readLine** (line 71). Note that the **FileReader** object was initialized with the **File** object **name** (line 66).

If the **File** object represents a directory (line 86), the program reads the contents of the directory into the program by using **File** method **list**, then displays the directory contents in the **JTextArea**.

The first output demonstrates a **File** object associated with the **jfc** directory from the Java 2 Software Development Kit. The second output of this program demonstrates a **File** object associated with the **readme.txt** file from the Java 2 Software Development Kit. In both cases, we specified an absolute path on our personal computer.

Note that the **** *separator character* is used to separate directories and files in the path. On a UNIX workstation, the separator character would be the **/** character. Java processes both characters identically in a path name. So, if we specified the path

```
c:\java/readme.txt
```

which uses one of each separator character, Java still processes the file properly.

Common Programming Error 16.2

Using **** *as a directory separator rather than* **** *in a string literal is a logic error. A single* **** *indicates that the* **** *and the next character represent an escape sequence. To insert a* **** *in a string literal, you must use* ****.

Good Programming Practice 16.6

When building ***String****s that represent path information, use* ***File.separatorChar*** *to obtain the local computer's proper separator character, rather than explicitly using* **/** *or* ****.

SUMMARY

- All data items processed by a computer are reduced to combinations of zeros and ones.
- The smallest data item in a computer (a bit) can assume the value **0** or the value **1**.
- Digits, letters and special symbols are called characters. The set of all characters used to write programs and represent data items on a particular computer is called that computer's character set. Every character in a computer's character set is represented as a pattern of **1**s and **0**s. (Characters in Java are Unicode characters composed of 2 bytes.)
- A field is a group of characters (or bytes) that conveys meaning.
- A record is a group of related fields.
- At least one field in a record is chosen as a record key to identify a record as belonging to a particular person or entity that is unique from all other records in the file.
- Java imposes no structure on a file. Notions like "record" do not exist in Java. The programmer must structure a file appropriately to meet the requirements of an application.
- A collection of programs designed to create and manage databases is called a database management system (DBMS).
- Java views each file as a sequential stream of bytes.

- Each file ends in some machine-dependent form of end-of-file marker.
- Streams provide communication channels between programs and files, memory or other programs across a network.
- Programs use classes from package **`java.io`** to perform Java file I/O. This package includes the definitions for the stream classes, such as **`FileInputStream`**, **`FileOutputStream`**, **`DataInputStream`** and **`DataOutputStream`**.
- Files are opened by instantiating objects of stream classes **`FileInputStream`**, **`FileOutputStream`**, **`RandomAccessFile`**, **`FileReader`** and **`FileWriter`**.
- **`InputStream`** (a subclass of **`Object`**) and **`OutputStream`** (a subclass of **`Object`**) are **`abstract`** classes that define methods for performing input and output, respectively.
- File input/output is done with **`FileInputStream`** (a subclass of **`InputStream`**) and **`FileOutputStream`** (a subclass of **`OutputStream`**).
- Pipes are synchronized communication channels between threads. A pipe is established between two threads. One thread sends data to another by writing to a **`PipedOutputStream`** (a subclass of **`OutputStream)`**. The target thread reads information from the pipe via a **`PipedInputStream`** (a subclass of **`InputStream`**).
- A **`PrintStream`** (a subclass of **`FilterOutputStream`**) performs output to the screen (or the "standard output" as defined by your local operating system). **`System.out`** is a **`PrintStream`** (as is **`System.err`**).
- A **`FilterInputStream`** filters an **`InputStream`**; a **`FilterOutStream`** filters an **`OutputStream`**. Filtering means simply that the filter stream provides additional functionality, such as buffering, monitoring of line numbers or aggregating of data bytes into meaningful primitive-data-type units.
- Reading data as raw bytes is fast but crude. Usually, programs read data as aggregates of bytes that form an **`int`**, a **`float`**, a **`double`**, and so on. To accomplish this, we use a **`DataInputStream`** (a subclass of class **`FilterInputStream`**).
- Interface **`DataInput`** is implemented by class **`DataInputStream`** and class **`RandomAccessFile`**; each needs to read primitive data types from a stream.
- **`DataInputStream`**s enable a program to read binary data from an **`InputStream`**.
- The **`DataInput`** interface includes methods **`read`** (for **`byte`** arrays), **`readBoolean`**, **`readByte`**, **`readChar`**, **`readDouble`**, **`readFloat`**, **`readFully`** (for **`byte`** arrays), **`readInt`**, **`readLine`**, **`readLong`**, **`readShort`**, **`readUnsignedByte`**, **`readUnsignedShort`**, **`readUTF`** (for Unicode) and **`skipBytes`**.
- The **`DataOutput`** interface is implemented by class **`DataOutputStream`** (a subclass of class **`FilterOutputStream`**) and class **`RandomAccessFile`**; each needs to write primitive data types to an **`OutputStream`**.
- **`DataOutputStream`**s enable a program to write binary data to an **`OutputStream`**. The **`DataOutput`** interface includes methods **`flush`**, **`size`**, **`write`** (for a byte), **`write`** (for a **`byte`** array), **`writeBoolean`**, **`writeByte`**, **`writeBytes`**, **`writeChar`**, **`writeChars`** (for Unicode **`String`**s), **`writeDouble`**, **`writeFloat`**, **`writeInt`**, **`writeLong`**, **`writeShort`** and **`writeUTF`**.
- Buffering is an I/O-performance-enhancement technique.
- With a **`BufferedOutputStream`** (a subclass of class **`FilterOutputStream`**), each output statement does not necessarily result in an actual physical transfer of data to the output device. Rather, each output operation is directed to a region in memory called a buffer that is large enough to hold the data of many output operations. Then, actual output to the output device is performed

in one large physical output operation each time the buffer fills. The output operations directed to the output buffer in memory are often called logical output operations.

- With a **BufferedInputStream**, many "logical" chunks of data from a file are read as one large physical input operation into a memory buffer. As a program requests each new chunk of data, it is taken from the buffer (this is sometimes referred to as a logical input operation). When the buffer is empty, the next physical input operation from the input device is performed to read in the next group of "logical" chunks of data. Thus, the number of physical input operations is small compared with the number of read requests issued by the program.
- With a **BufferedOutputStream** a partially filled buffer can be forced out to the device at any time with an explicit **flush**.
- The **ObjectInput** interface is similar to the **DataInput** interface, but includes additional methods to read **Object**s from **InputStream**s.
- The **ObjectOutput** interface is similar to the **DataOutput** interface, but includes additional methods to write **Object**s to **OutputStream**s.
- The **ObjectInputStream** and **ObjectOutputStream** classes implement the **ObjectInput** and **ObjectOutput** interfaces, respectively.
- A **PushbackInputStream** is a subclass of class **FilterInputStream**. The application reading a **PushbackInputStream** reads bytes from the stream and forms aggregates consisting of several bytes. Sometimes, to determine that one aggregate is complete, the application must read the first character "past the end" of the first aggregate. Once the program has determined that the current aggregate is complete, the extra character is "pushed back" onto the stream.
- **PushbackInputStream**s are used by programs, like compilers, that parse their inputs—that is, break them into meaningful units (such as the keywords, identifiers and operators that the Java compiler must recognize).
- A **RandomAccessFile** (a subclass of **Object**) is useful for such direct-access applications as transaction-processing applications, like airline-reservations systems and point-of-sale systems.
- With a sequential-access file, each successive input/output request reads or writes the next consecutive set of data in the file.
- With a random-access file, each successive input/output request might be directed to any part of the file, perhaps one widely separated from the part of the file referenced in the previous request.
- Direct-access applications provide rapid access to specific data items in large files; such applications are often used while people are waiting for answers—these answers must be made available quickly, or the people might become impatient and "take their business elsewhere."
- A **ByteArrayInputStream** (a subclass of **abstract** class **InputStream**) performs its inputs from a **byte** array in memory.
- A **ByteArrayOutputStream** (a subclass of **abstract** class **OutputStream**) outputs to a **byte** array in memory.
- An application of **byte**-array input/output is data validation. A program can input an entire line at a time from the input stream into a **byte** array. Then, a validation routine can scrutinize the contents of the **byte** array and correct the data, if necessary. The program can now proceed to input from the **byte** array, knowing that the input data is in the proper format.
- A **StringBufferInputStream** (a subclass of **abstract** class **InputStream**) inputs from a **StringBuffer** object.
- A **SequenceInputStream** (a subclass of **abstract** class **InputStream**) enables several **InputStream**s to be concatenated so that the program will see the group as one continuous **InputStream**. As the end of each input stream is reached, the stream is closed, and the next stream in the sequence is opened.

- Class **BufferedReader** and class **BufferedWriter** enable efficient buffering for character-based streams.
- Class **CharArrayReader** and class **CharArrayWriter** read and write a stream of characters to a character array.
- A **PushbackReader** (a subclass of **abstract** class **FilterReader**) enables characters to be placed back on a character stream. A **LineNumberReader** (a subclass of **BufferedReader**) is a buffered character-stream that keeps track of line numbers (e.g., a newline, a return or a carriage-return line-feed combination).
- Class **FileReader** (a subclass of **InputStreamReader**) and class **FileWriter** (a subclass of **OutputStreamWriter**) read and write characters to a file. Class **PipedReader** and class **PipedWriter** are piped-character streams. Class **StringReader** and **StringWriter** read and write characters to **String**s. A **PrintWriter** writes characters to a stream.
- Class **File** enables programs to obtain information about a file or directory.
- Files are opened for output by creating a **FileOutputStream** class object. One argument is passed to the constructor—the filename. Existing files are truncated, and all data in the file is lost. Nonexistent files are created.
- A program can process no files, one file or several files. Each file has a unique name and is associated with an appropriate file stream object. All file-processing methods must refer to a file with the appropriate object.
- A file-position pointer indicates the position in the file from which the next input is to occur or at which the next output is to be placed.
- A convenient way to implement random-access files is by using only fixed-length records. Using this technique, a program can quickly calculate the exact location of a record relative to the beginning of the file.
- Data can be inserted in a random-access file without destroying other data in the file. Data can be updated or deleted without rewriting the entire file.
- The **RandomAccessFile** class has the same capabilities for input and output as the **DataInputStream** and **DataOutputStream** classes and also supports seeking to a specific byte position in the file, with method **seek**.

TERMINOLOGY

absolute path
alphabetic field
alphanumeric field
binary digit
bit
buffer
BufferedInputStream class
BufferedOutputStream class
BufferedReader class
BufferedWriter class
buffering
byte
ByteArrayInputStream class
ByteArrayOutputStream class
CANCEL_OPTION constant
canRead method of **File** class
canWrite method of **File** class
chaining stream objects
character field
character set
CharArrayReader class
CharArrayWriter class
close a file
close method
data hierarchy
data validation
database
database management system (DBMS)
DataInput interface
DataOutput interface
decimal digit
direct-access applications

DIRECTORIES_ONLY constant
directory
end-of-file
end-of-file marker
EndOfFileException
exists method of **File** class
field
file
File class
file name
FileInputStream class
FileOutputStream class
file-position pointer
FileReader class
FILES_AND_DIRECTORIES constant
FILES_ONLY constant
FileWriter class
FilterInputStream class
FilterOutputStream class
FilterReader class
flush
getAbsolutePath method of **File** class
getName method of **File** class
getParent method of **File** class
getPath method of **File** class
getSelectedFile method
input stream
InputStream class
InputStreamReader class
instant-access application
IOException
isAbsolute method of **File** class
isDirectory method of **File** class
isFile method of **File** class
JFileChooser class
lastModified method of **File** class
length method of **File** class
LineNumberReader class
list method of **File** class
logical input operation
logical output operation
memory buffer
modal dialog
numeric field
ObjectInput interface
ObjectInputStream class
ObjectOutput interface
ObjectOutputStream class
open a file
output stream
OutputStream class
OutputStreamWriter class
partially filled buffer
persistent data
physical input operation
physical output operation
pipe
PipedInputStream class
PipedOutputStream class
PipedReader class
PipedWriter class
PrintStream class
PrintWriter class
PushbackInputStream class
PushbackReader class
r file open mode
random-access file
RandomAccessFile class
read method
readBoolean method
readByte method
readChar method
readDouble method
Reader class
readFloat method
readFully method
readInt method
readLong method
readObject method
readShort method
readUnsignedByte method
readUnsignedShort method
record
record key
relative path
root directory
rw file open mode
seek method
SequenceInputStream class
sequential-access file
Serializable interface
setFileSelectionMode method
showOpenDialog method
showSaveDialog method
standard output
StringReader class
StringWriter class
System.err (standard error stream)
System.in (standard input stream)
System.out (standard output stream)

transaction-processing systems
truncate an existing file
Unicode character set
write method
writeBoolean method
writeByte method
writeBytes method
writeChar method
writeChars method
writeDouble method
writeFloat method
writeInt method
writeLong method
writeObject method
Writer class
writeShort method

SELF-REVIEW EXERCISES

16.1 Fill in the blanks in each of the following statements:

a) Ultimately, all data items processed by a computer are reduced to combinations of _____ and _____.
b) The smallest data item a computer can process is called a _____.
c) A _____ is a group of related records.
d) Digits, letters and special symbols are referred to as _____.
e) A group of related files is called a _____.
f) Method _____ of the file stream classes **FileOutputStream**, **FileInputStream**, and **RandomAccessFile** closes a file.
g) **RandomAccessFile** method _____ reads an integer from the specified stream.
h) **RandomAccessFile** method _____ reads a line of text from the specified stream.
i) **RandomAccessFile** method _____ sets the file-position pointer to a specific location in a file for input or output.

16.2 State which of the following are *true* and which are *false*. If *false*, explain why.

a) The programmer must explicitly create the **System.in**, **System.out** and **System.err** objects.
b) If the file-position pointer points to a location in a sequential file other than the beginning of the file, the file must be closed and reopened to read from the beginning of the file.
c) It is not necessary to search through all the records in a random-access file to find a specific record.
d) Records in random-access files must be of uniform length.
e) Method **seek** must seek relative to the beginning of a file.

16.3 Assume that each of the following statements applies to the same program.

a) Write a statement that opens file **"oldmast.dat"** for input; use **ObjectInputStream** object **inOldMaster** chained to a **FileInputStream** object.
b) Write a statement that opens file **"trans.dat"** for input; use **ObjectInputStream** object **inTransaction** chained to a **FileInputStream** object.
c) Write a statement that opens file **"newmast.dat"** for output (and creation); use **ObjectOutputStream** object **outNewMaster** chained to a **FileOutputStream**.
d) Write a set of statements that read a record from the file **"oldmast.dat"**. The record consists of integer **accountNumber**, string **name** and floating-point **currentBalance**; use **ObjectInputStream** object **inOldMaster**.
e) Write a set of statements that read a record from the file **"trans.dat"**. The record consists of integer **accountNumber** and floating-point **dollarAmount**; use **ObjectInputStream** object **inTransaction**.
f) Write a set of statements that outputs a record to the file **"newmast.dat"**. The record consists of integer **accountNumber**, string **name** and floating point **currentBalance**; use **DataOutputStream** object **outNewMaster**.

16.4 Find the error and show how to correct it in each of the following.

a) Assume **account**, **company** and **amount** are declared.

```
ObjectOutputStream outputStream;

outputStream.writeInt( account );
outputStream.writeChars( company );
outputStream.writeDouble( amount );
```

b) The following statement should read a record from the file **"payables.dat"**. The **ObjectInputStream** object **inPayable** refers to this file, and **FileInputStream** object **inReceivable** refers to the file **"receivables.dat"**.

```
account = inReceivable.readInt();
companyID = inReceivable.readLong();
amount = inReceivable.readDouble();
```

ANSWERS TO SELF-REVIEW EXERCISES

16.1 a) 1s, 0s. b) bit. c) file. d) characters. e) database. f) **close**. g) **readInt**. h) **readLine**. i) **seek**.

16.2 a) False. These three streams are created automatically for the programmer.
b) True.
c) True.
d) False. Records in a random-access file are normally of uniform length.
e) True.

16.3 a)
```
ObjectInputStream inOldMaster;
inOldMaster = new ObjectInputStream(
   new FileInputStream( "oldmast.dat" ) );
```
b)
```
ObjectInputStream inTransaction;
inTransaction = new ObjectInputStream(
   new FileInputStream( "trans.dat" ) );
```
c)
```
ObjectOutputStream outNewMaster;
outNewMaster = new ObjectOutputStream(
   new FileOutputStream( "newmast.dat" ) );
```
d)
```
accountNumber = inOldMaster.readInt();
name = inOldMaster.readUTF();
currentBalance = inOldMaster.readDouble();
```
e)
```
accountNumber = inTransaction.readInt();
dollarAmount = inTransaction.readDouble();
```
f)
```
outNewMaster.writeInt( accountNumber );
outNewMaster.writeUTF( name );
outNewMaster.writeDouble( currentBalance );
```

16.4 a) Error: The file has not been opened before the attempt is made to output data to the stream.
Correction: Create a new **ObjectOutputStream** object chained to a **FileOutputStream** object to open the file for output.

b) Error: The incorrect **FileInputStream** object is being used to read a record from file **"payables.dat"**.
Correction: Use object **inPayable** to refer to **"payables.dat"**.

EXERCISES

16.5 Fill in the blanks in each of the following:

a) Computers store large amounts of data on secondary storage devices as _____.
b) A _____ is composed of several fields.
c) A field that may contain only digits, letters and blanks is called an _____ field.
d) To facilitate the retrieval of specific records from a file, one field in each record is chosen as a _____.
e) The vast majority of information stored in computer systems is stored in _____ files.
f) The standard stream objects are _____, _____ and _____.

16.6 State which of the following are *true* and which are *false*. If *false*, explain why.

a) The impressive functions performed by computers essentially involve the manipulation of zeros and ones.
b) People specify programs and data items as characters; computers then manipulate and process these characters as groups of zeros and ones.
c) A person's 5-digit zip code is an example of a numeric field.
d) A person's street address is generally considered to be an alphabetic field.
e) Data items represented in computers form a data hierarchy in which data items become larger and more complex as we progress from fields to characters to bits, etc.
f) A record key identifies a record as belonging to a particular field.
g) Companies store all their information in a single file to facilitate computer processing.
h) When a program creates a file, the file is automatically retained by the computer for future reference.

16.7 Exercise 16.3 asked the reader to write a series of single statements. Actually, these statements form the core of an important type of file-processing program, namely, a file-matching program. In commercial data processing, it is common to have several files in each application system. In an accounts receivable system, for example, there is generally a master file containing detailed information about each customer, such as the customer's name, address, telephone number, outstanding balance, credit limit, discount terms, contract arrangements and possibly a condensed history of recent purchases and cash payments.

a) As transactions occur (i.e., sales are made and cash payments arrive in the mail), they are entered into a file. At the end of each business period (i.e., a month for some companies, a week for others, and a day in some cases) the file of transactions (called **`"trans.dat"`** in Exercise 16.3) is applied to the master file (called **`"oldmast.dat"`** in Exercise 16.3), thus updating each account's record of purchases and payments. During an updating run, the master file is rewritten as a new file (**`"newmast.dat"`**), which is then used at the end of the next business period to begin the updating process again.
b) File-matching programs must deal with certain problems that do not exist in single-file programs. For example, a match does not always occur. A customer on the master file might not have made any purchases or cash payments in the current business period; therefore, no record for this customer will appear on the transaction file. Similarly, a customer who did make some purchases or cash payments could have just moved to this community, and the company might not have had a chance to create a master record for this customer.
c) Use the statements in Exercise 16.3 as a basis for writing a complete file-matching accounts receivable program. Use the account number on each file as the record key for matching purposes. Assume that each file is a sequential file with records stored in increasing account-number order.
d) When a match occurs (i.e., records with the same account number appear on both the master file and the transaction file), add the dollar amount on the transaction file to the

current balance on the master file, and write the **"newmast.dat"** record. (Assume that purchases are indicated by positive amounts on the transaction file, payments by negative amounts.) When there is a master record for a particular account but no corresponding transaction record, merely write the master record to **"newmast.dat"**. When there is a transaction record but no corresponding master record, print the message **"Unmatched transaction record for account number …"** (fill in the account number from the transaction record).

16.8 After writing the program of Exercise 16.7, write a simple program to create some test data for checking out the program. Use the sample account data in Fig. 16.23 and Fig. 16.24. Run the program of Exercise 16.7, using the files of test data created in this exercise. Print the new master file. Check that the accounts have been updated correctly.

16.9 It is possible (actually common) to have several transaction records with the same record key. This occurs because a particular customer might make several purchases and cash payments during a business period. Rewrite your accounts receivable file-matching program of Exercise 16.7 to provide for the possibility of handling several transaction records with the same record key. Modify the test data of Exercise 16.8 to include the additional transaction records in Fig. 16.25.

Master file Account number	Name	Balance
100	Alan Jones	348.17
300	Mary Smith	27.19
500	Sam Sharp	0.00
700	Suzy Green	-14.22

Fig. 16.23 Sample data for master file.

Transaction file Account number	Transaction amount
100	27.14
300	62.11
400	100.56
900	82.17

Fig. 16.24 Sample data for transaction file.

Account number	Dollar amount
300	83.89
700	80.78
700	1.53

Fig. 16.25 Additional transaction records.

16.10 You are the owner of a hardware store and need to keep an inventory that can tell you what different tools you have, how many of each you have on hand and the cost of each one. Write a program that initializes the random-access file **`"hardware.dat"`** to one hundred empty records, lets you input the data concerning each tool, enables you to list all your tools, lets you delete a record for a tool that you no longer have and lets you update *any* information in the file. The tool identification number should be the record number. Use the information in Fig. 16.26 to start your file.

16.11 *(Telephone Number Word Generator)* Standard telephone keypads contain the digits 0 through 9. The numbers 2 through 9 each have three letters associated with them (see Fig. 16.27).

Many people find it difficult to memorize phone numbers, so they use the correspondence between digits and letters to develop seven-letter words that correspond to their phone numbers. For example, a person whose telephone number is 686-2377 might use the correspondence indicated in Fig. 16.27 to develop the seven-letter word "NUMBERS." Each seven-letter word corresponds to exactly one seven-digit telephone number. The restaurant wishing to increase its takeout business could surely do so with the number 825-3688 (i.e., "TAKEOUT").

Record #	Tool name	Quantity	Cost
3	Electric sander	18	35.99
19	Hammer	128	10.00
26	Jig saw	16	14.25
39	Lawn mower	10	79.50
56	Power saw	8	89.99
76	Screwdriver	236	4.99
81	Sledge hammer	32	19.75
88	Wrench	65	6.48

Fig. 16.26 Data for Exercise 16.10.

Digit	Letters
2	A B C
3	D E F
4	G H I
5	J K L
6	M N O
7	P R S
8	T U V
9	W X Y

Fig. 16.27 Telephone keypad digits and letters.

Each seven-letter phone number corresponds to many separate seven-letter words. Unfortunately, most of these represent unrecognizable juxtapositions of letters. It is possible, however, that the owner of a barber shop would be pleased to know that the shop's telephone number, 424-7288, corresponds to "HAIRCUT." The owner of a liquor store would, no doubt, be delighted to find that the store's number, 233-7226, corresponds to "BEERCAN." A veterinarian with the phone number 738-2273 would be pleased to know that the number corresponds to the letters "PETCARE." An automotive dealership would be pleased to know that the dealership number, 639-2277, corresponds to "NEWCARS."

Write a program that, given a seven-digit number, writes to a file every possible seven-letter word combination corresponding to that number. There are 2187 (3^7) such combinations. Avoid phone numbers with the digits 0 and 1.

17

Networking

Objectives

- To understand Java networking with URIs, sockets and datagrams.
- To implement Java networking applications by using sockets and datagrams.
- To understand how to implement Java clients and servers that communicate with one another.
- To understand how to implement network-based collaborative applications.
- To construct a multithreaded server.

If the presence of electricity can be made visible in any part of a circuit, I see no reason why intelligence may not be transmitted instantaneously by electricity.
Samuel F. B. Morse

Mr. Watson, come here, I want you.
Alexander Graham Bell

What networks of railroads, highways and canals were in another age, the networks of telecommunications, information and computerization … are today.
Bruno Kreisky, Austrian Chancellor

Science may never come up with a better office-communication system than the coffee break.
Earl Wilson

It's currently a problem of access to gigabits through punybaud.
J. C. R. Licklider

Outline

17.1 Introduction
17.2 Manipulating URIs
17.3 Reading a File on a Web Server
17.4 Establishing a Simple Server Using Stream Sockets
17.5 Establishing a Simple Client Using Stream Sockets
17.6 Client/Server Interaction with Stream Socket Connections
17.7 Connectionless Client/Server Interaction with Datagrams
17.8 Client/Server Tic-Tac-Toe Using a Multithreaded Server
17.9 Security and the Network
17.10 DeitelMessenger Chat Server and Client
17.10.1 DeitelMessengerServer and Supporting Classes
17.10.2 DeitelMessenger Client and Supporting Classes
17.11 (Optional) Discovering Design Patterns: Design Patterns Used in Packages `java.io` and `java.net`
17.11.1 Creational Design Patterns
17.11.2 Structural Design Patterns
17.11.3 Architectural Patterns
17.11.4 Conclusion

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

17.1 Introduction

There is much excitement over the Internet and the World Wide Web. The Internet ties the "information world" together. The World Wide Web makes the Internet easy to use and gives it the flair and sizzle of multimedia. Organizations see the Internet and the Web as crucial to their information-systems strategies. Java provides a number of built-in networking capabilities that make it easy to develop Internet-based and Web-based applications. Not only can Java specify parallelism through multithreading, but it can enable programs to search the world for information and to collaborate with programs running on other computers internationally, nationally or just within an organization. Java can enable applets and applications to communicate with one another (subject to security constraints).

Networking is a massive and complex topic. Computer science and computer engineering students will typically take a full-semester, upper level course in computer networking and continue with further study at the graduate level. Java provides a rich complement of networking capabilities and will likely be used as an implementation vehicle in computer networking courses. In *Java How to Program, Fourth Edition*, we introduce a portion of Java's networking concepts and capabilities. For more advanced networking capabilities, refer to our book *Advanced Java 2 Platform How to Program*.

Java's networking capabilities are grouped into several packages. The fundamental networking capabilities are defined by classes and interfaces of package **`java.net`**,

through which Java offers *socket-based communications* that enable applications to view networking as streams of data. The classes and interfaces of package **`java.net`** also offer *packet-based communications* that enable individual *packets* of information to be transmitted—this is commonly used to transmit audio and video over the Internet. In this chapter, we show how to create and manipulate sockets and how to communicate with packets of data.

Our discussion of networking focuses on both sides of a *client-server relationship*. The *client* requests that some action be performed, and the *server* performs the action and responds to the client. A common implementation of the request-response model is between World Wide Web browsers and World Wide Web servers. When a user selects a Web site to browse through a browser (the client application), a request is sent to the appropriate Web server (the server application). The server normally responds to the client by sending an appropriate HTML Web page.

We demonstrate the Swing GUI component ***`JEditorPane`*** and its ability to render an HTML document downloaded from the World Wide Web. We also introduce Java's a *socket-based communications,* which enable applications to view networking as if it were file I/O—a program can read from a *socket* or write to a socket as simply as reading from a file or writing to a file. We show how to create and manipulate sockets.

Java provides *stream sockets* and *datagram sockets.* With *stream sockets*, a process establishes a *connection* to another process. While the connection is in place, data flows between the processes in continuous *streams*. Stream sockets are said to provide a *connection-oriented service*. The protocol used for transmission is the popular *TCP (Transmission Control Protocol)*.

With *datagram sockets*, individual *packets* of information are transmitted. This is not the right protocol for everyday users, because, unlike TCP, the protocol used—*UDP*, the *User Datagram Protocol*—is a *connectionless service*, and it does not guarantee that packets arrive in any particular order. In fact, packets can be lost, can be duplicated and can even arrive out of sequence. So, with UDP, significant extra programming is required on the user's part to deal with these problems (if the user chooses to do so). UDP is most appropriate for network applications that do not require the error checking and reliability of TCP. Stream sockets and the TCP protocol will be the most desirable for the vast majority of Java programmers.

Performance Tip 17.1

Connectionless services generally offer greater performance, but less reliability than connection-oriented services.

Portability Tip 17.1

The TCP protocol and its related set of protocols enable a great variety of heterogeneous computer systems (i.e., computer systems with different processors and different operating systems) to intercommunicate.

The chapter ends with a case study in which we implement a client/server chat application similar to the instant-messaging services popular on the Web today. The program incorporates many networking techniques introduced in this chapter. The program also introduces *multicasting*, in which a server can *publish* information and clients can *subscribe* to that information. Each time the server publishes more information, all subscribers receive that information. Throughout the examples of this chapter, we will see that many of the networking details are handled by the Java classes we use.

17.2 Manipulating URIs

The Internet offers many protocols. The *HyperText Transfer Protocol* (*HTTP*) that forms the basis of the World Wide Web uses *URIs* (*Uniform Resource Identifiers*) to locate data on the Internet. URIs frequently are called *URLs* (*Uniform Resource Locators*). Actually, a URL is a type of URI. Common URIs refer to files or directories and can reference objects that perform complex tasks, such as database lookups and Internet searches. If you know the URI of publicly available HTML files anywhere on the World Wide Web, you can access that data through HTTP. Java makes it easy to manipulate URIs. Using a URI that refers to the exact location of a resource (such as a Web page) as an argument to the **`showDocument`** method of interface **`AppletContext`** causes the browser in which the applet is executing to display the resource at the specified URI. The applet of Fig. 17.1 and Fig. 17.2 enables the user to select a Web page from a **`JList`** and causes the browser to display the corresponding page.

This applet takes advantage of *applet parameters* specified in the HTML document that invokes the applet. When browsing the World Wide Web, often you will come across applets that are in the public domain—you can use them free of charge on your own Web pages (normally in exchange for crediting the applet's creator). One common feature of such applets is the ability to customize the applet via parameters that are supplied from the HTML file that invokes the applet. For example, Fig. 17.1 contains the HTML that invokes the applet **`SiteSelector`** in Fig. 17.2. The HTML document contains eight parameters specified with the **`param`** *element*—these lines must appear between the starting and ending **`applet`** tags. The applet can read these values and use them to customize itself. Any number of **`param`** tags can appear between the starting and ending **`applet`** tags. Each parameter has a **`name`** and a **`value`**. **`Applet`** method **`getParameter`** retrieves the **`value`** associated with a specific parameter and returns the **`value`** as a **`String`**. The argument passed to **`getParameter`** is a **`String`** containing the name of the parameter in the **`param`** tag. In this example, parameters represent the title of each Web site the user can select and the location of each site. Any number of parameters can be specified. However, these parameters must be named **`title`**#, where the value of # starts at **`0`** and increments by one for each new title. Each title should have a corresponding location parameter of the form **`location`**#, where the value of # starts at **`0`** and increments by one for each new location. The statement

```
1  <html>
2  <title>Site Selector</title>
3  <body>
4     <applet code = "SiteSelector.class" width = "300" height = "75">
5        <param name = "title0" value = "Java Home Page">
6        <param name = "location0" value = "http://java.sun.com/">
7        <param name = "title1" value = "Deitel">
8        <param name = "location1" value = "http://www.deitel.com/">
9        <param name = "title2" value = "JGuru">
10       <param name = "location2" value = "http://www.jGuru.com/">
11       <param name = "title3" value = "JavaWorld">
12       <param name = "location3" value = "http://www.javaworld.com/">
13    </applet>
14 </body>
15 </html>
```

Fig. 17.1 HTML document to load **`SiteSelector`** applet.

```
String title = getParameter( "title0" );
```

gets the value associated with the **"title0"** parameter and assigns it to **String** reference **title**. If there is not a **param** tag containing the specified parameter, **getParameter** returns **null**.

The applet (Fig. 17.2) obtains from the HTML document (Fig. 17.1) the choices that will be displayed in the applet's **JList**. Class **SiteSelector** uses a ***Hashtable*** (package ***java.util***) to store the World Wide Web site names and URIs. A **Hashtable** stores *key/value pairs*. The program uses the *key* to store and retrieve the associated *value* in the **Hashtable**. In this example, the *key* is the **String** in the **JList** that represents the Web site name, and the value is a **URL** object that stores the URI of the Web site to display in the browser. Class **Hashtable** provides two methods of importance in this example—***put*** and ***get***. Method **put** takes two arguments—a key and its associated value—and places the value in the **Hashtable** at a location determined by the key. Method **get** takes one argument—a key—and retrieves the value (as an **Object** reference) associated with the key. Class **SiteSelector** also contains a **Vector** (package **java.util**) in which the site names are placed so they can be used to initialize the **JList** (one version of the **JList** constructor receives a **Vector** object). A **Vector** is a dynamically resizable array of **Object**s. Class **Vector** provides method ***add*** to add a new element to the end of the **Vector**. Classes **Hashtable** and **Vector** are discussed in detail in Chapter 20.

Lines 23–24 in method **init** (lines 20–63) create the **Hashtable** and **Vector** objects. Line 27 calls our utility method **getSitesFromHTMLParameters** (lines 66–108) to obtain the HTML parameters from the HTML document that invoked the applet.

In method **getSitesFromHTMLParameters**, line 75 uses **Applet** method **getParameter** to obtain a Web site title. If the **title** is not **null**, the loop at lines 78–106 begins executing. Line 81 uses **Applet** method **getParameter** to obtain the corresponding location. Line 87 uses the **location** as the initial value of a new **URL** object. The **URL** constructor determines whether the **String** passed as an argument represents a valid Uniform Resource Identifier. If not, the **URL** constructor throws a ***MalformedURLException***. Notice that the **URL** constructor must be called in a **try** block. If the **URL** constructor generates a **MalformedURLException**, the call to **printStackTrace** (line 98) causes the program to display a stack trace. Then the program attempts to obtain the next Web site title. The program does not add the site for the invalid URI to the **Hashtable**, so the title will not be displayed in the **JList**.

Common Programming Error 17.1

*A **MalformedURLException** is thrown when a **String** that is not in proper URI format is passed to a **URL** constructor.*

For a proper **URL**, line 90 places the **title** and **URL** into the **Hashtable**, and line 93 adds the **title** to the **Vector**. Line 104 gets the next title from the HTML document. When the call to **getParameter** at line 104 returns **null**, the loop terminates.

When method **getSitesFromHTMLParameters** returns to **init**, lines 30–61 construct the applet's GUI. Lines 31–32 add the **JLabel** "**Choose a site to browse**" to the **NORTH** of the content pane's **BorderLayout**. Lines 36–58 register an instance of an anonymous inner class that implements **ListSelectionListener** to handle the **siteChooser**'s events. Lines 60–61 add **siteChooser** to the **CENTER** of the content pane's **BorderLayout**.

```
1  // Fig. 17.2: SiteSelector.java
2  // This program uses a button to load a document from a URL.
3
4  // Java core packages
5  import java.net.*;
6  import java.util.*;
7  import java.awt.*;
8  import java.applet.AppletContext;
9
10 // Java extension packages
11 import javax.swing.*;
12 import javax.swing.event.*;
13
14 public class SiteSelector extends JApplet {
15    private Hashtable sites;     // site names and URLs
16    private Vector siteNames;    // site names
17    private JList siteChooser;  // list of sites to choose from
18
19    // read HTML parameters and set up GUI
20    public void init()
21    {
22       // create Hashtable and Vector
23       sites = new Hashtable();
24       siteNames = new Vector();
25
26       // obtain parameters from HTML document
27       getSitesFromHTMLParameters();
28
29       // create GUI components and layout interface
30       Container container = getContentPane();
31       container.add( new JLabel( "Choose a site to browse" ),
32          BorderLayout.NORTH );
33
34       siteChooser = new JList( siteNames );
35
36       siteChooser.addListSelectionListener(
37
38          new ListSelectionListener() {
39
40             // go to site user selected
41             public void valueChanged( ListSelectionEvent event )
42             {
43                // get selected site name
44                Object object = siteChooser.getSelectedValue();
45
46                // use site name to locate corresponding URL
47                URL newDocument = ( URL ) sites.get( object );
48
49                // get reference to applet container
50                AppletContext browser = getAppletContext();
51
52                // tell applet container to change pages
53                browser.showDocument( newDocument );
```

Fig. 17.2 Loading a document from a URL into a browser (part 1 of 3).

```
54              }  // end method valueChanged
55
56           }  // end anonymous inner class
57
58        ); // end call to addListSelectionListener
59
60        container.add( new JScrollPane( siteChooser ),
61           BorderLayout.CENTER );
62
63     }  // end method init
64
65     // obtain parameters from HTML document
66     private void getSitesFromHTMLParameters()
67     {
68        // look for applet parameters in the HTML document
69        // and add sites to Hashtable
70        String title, location;
71        URL url;
72        int counter = 0;
73
74        // obtain first site title
75        title = getParameter( "title" + counter );
76
77        // loop until no more parameters in HTML document
78        while ( title != null ) {
79
80           // obtain site location
81           location = getParameter( "location" + counter );
82
83           // place title/URL in Hashtable and title in Vector
84           try {
85
86              // convert location to URL
87              url = new URL( location );
88
89              // put title/URL in Hashtable
90              sites.put( title, url );
91
92                 // put title in Vector
93              siteNames.add( title );
94           }
95
96           // process invalid URL format
97           catch ( MalformedURLException urlException ) {
98              urlException.printStackTrace();
99           }
100
101          ++counter;
102
103          // obtain next site title
104          title = getParameter( "title" + counter );
105
106       }  // end while
```

Fig. 17.2 Loading a document from a URL into a browser (part 2 of 3).

```
107
108     }  // end method getSitesFromHTMLParameters
109
110  }  // end class SiteSelector
```

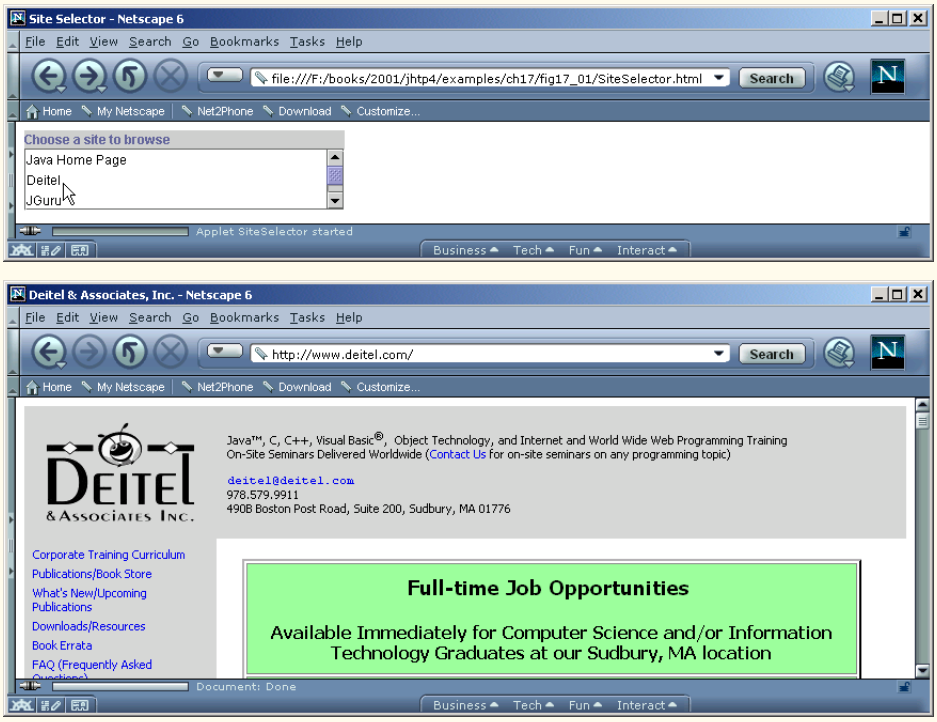


Fig. 17.2 Loading a document from a URL into a browser (part 3 of 3).

When the user selects one of the Web sites in **siteChooser**, the program calls method **valueChanged** (lines 41–54). Line 44 obtains the selected site name from the **JList**. Line 47 passes the selected site name (the *key*) to **Hashtable** method **get**, which locates and returns an **Object** reference to the corresponding **URL** object (the *value*). The **URL** cast operator converts the reference to a **URL** that can be assigned to reference **newDocument**.

Line 50 uses **Applet** method **getAppletContext** to get a reference to an **AppletContext** object that represents the applet container. Line 53 uses the **AppletContext** reference **browser** to invoke **AppletContext** method ***showDocument***, which receives a **URL** object as an argument and passes it to the **AppletContext** (i.e., the browser). The browser displays in the current browser window the World Wide Web resource associated with that **URL**. In this example, all the resources are HTML documents.

For programmers familiar with *HTML frames*, there is a second version of **AppletContext** method **showDocument** that enables an applet to specify the so-called *target frame* in which to display the World Wide Web resource. The second version of **showDocument** takes two arguments—a **URL** object specifying the resource to display and a **String** representing the target frame. There are some special target frames that can be used as the second argument. The target frame ***_blank*** results in a new Web browser

window to display the content from the specified URI. The target frame ***_self*** specifies that the content from the specified URI should be displayed in the same frame as the applet (the applet's HTML page is replaced in this case). The target frame ***_top*** specifies that the browser should remove the current frames in the browser window, then display the content from the specified URI in the current window. For more information on HTML and frames, see the *World Wide Web Consortium (W3C)* Web site

http://www.w3.org

[Note: This applet must be run from a World Wide Web browser, such as Netscape *Navigator* or Microsoft *Internet Explorer*, to see the results of displaying another Web page. The **appletviewer** is capable only of executing applets—it ignores all other HTML tags. If the Web sites in the program contained Java applets, only those applets would appear in the **appletviewer** when the user selects a Web site. Each applet would execute in a separate **appletviewer** window. Of the browsers mentioned here, only Netscape Navigator 6 currently supports the features of Java 2. You will need to use the Java Plug-in (discussed in Chapter 3) to execute this applet in Microsoft *Internet Explorer* or older versions of Netscape *Navigator*.]

17.3 Reading a File on a Web Server

The application of Fig. 17.3 uses Swing GUI component ***JEditorPane*** (from package **javax.swing**) to display the contents of a file on a Web server. The user inputs the URI in the **JTextField** at the top of the window, and the program displays the corresponding document (if it exists) in the **JEditorPane**. Class **JEditorPane** is able to render both plain text and HTML-formatted text, so this application acts as a simple Web browser. The application also demonstrates how to process ***HyperlinkEvent****s* when the user clicks a hyperlink in the HTML document. The screen captures in Fig. 17.3 illustrate that the **JEditorPane** can display both simple text (the first screen) and HTML text (the second screen). The techniques shown in this example also can be used in applets. However, applets are allowed to read files only on the server from which the applet was downloaded.

```
1  // Fig. 17.3: ReadServerFile.java
2  // This program uses a JEditorPane to display the
3  // contents of a file on a Web server.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.net.*;
9  import java.io.*;
10
11 // Java extension packages
12 import javax.swing.*;
13 import javax.swing.event.*;
14
15 public class ReadServerFile extends JFrame {
16    private JTextField enterField;
17    private JEditorPane contentsArea;
```

Fig. 17.3 Reading a file by opening a connection through a **URL** (part 1 of 4)

```
18
19    // set up GUI
20    public ReadServerFile()
21    {
22       super( "Simple Web Browser" );
23
24       Container container = getContentPane();
25
26       // create enterField and register its listener
27       enterField = new JTextField( "Enter file URL here" );
28
29       enterField.addActionListener(
30
31          new ActionListener() {
32
33             // get document specified by user
34             public void actionPerformed( ActionEvent event )
35             {
36                getThePage( event.getActionCommand() );
37             }
38
39          }  // end anonymous inner class
40
41       ); // end call to addActionListener
42
43       container.add( enterField, BorderLayout.NORTH );
44
45       // create contentsArea and register HyperlinkEvent listener
46       contentsArea = new JEditorPane();
47       contentsArea.setEditable( false );
48
49       contentsArea.addHyperlinkListener(
50
51          new HyperlinkListener() {
52
53             // if user clicked hyperlink, go to specified page
54             public void hyperlinkUpdate( HyperlinkEvent event )
55             {
56                if ( event.getEventType() ==
57                     HyperlinkEvent.EventType.ACTIVATED )
58                   getThePage( event.getURL().toString() );
59             }
60
61          }  // end anonymous inner class
62
63       ); // end call to addHyperlinkListener
64
65       container.add( new JScrollPane( contentsArea ),
66          BorderLayout.CENTER );
67
68       setSize( 400, 300 );
69       setVisible( true );
70    }
```

Fig. 17.3 Reading a file by opening a connection through a **URL** (part 2 of 4)

```
71
72     // load document; change mouse cursor to indicate status
73     private void getThePage( String location )
74     {
75        // change mouse cursor to WAIT_CURSOR
76        setCursor( Cursor.getPredefinedCursor(
77           Cursor.WAIT_CURSOR ) );
78
79        // load document into contentsArea and display location in
80        // enterField
81        try {
82           contentsArea.setPage( location );
83           enterField.setText( location );
84        }
85
86        // process problems loading document
87        catch ( IOException ioException ) {
88           JOptionPane.showMessageDialog( this,
89              "Error retrieving specified URL",
90              "Bad URL", JOptionPane.ERROR_MESSAGE );
91        }
92
93        setCursor( Cursor.getPredefinedCursor(
94           Cursor.DEFAULT_CURSOR ) );
95     }
96
97     // begin application execution
98     public static void main( String args[] )
99     {
100       ReadServerFile application = new ReadServerFile();
101
102       application.setDefaultCloseOperation(
103          JFrame.EXIT_ON_CLOSE );
104    }
105
106 }  // end class ReadServerFile
```

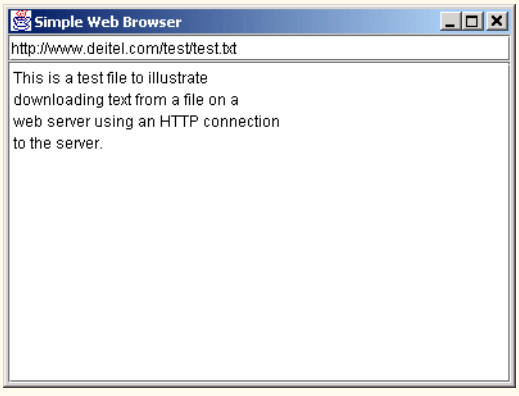


Fig. 17.3 Reading a file by opening a connection through a **URL** (part 3 of 4)

Fig. 17.3 Reading a file by opening a connection through a **URL** (part 4 of 4)

The application class **ReadServerFile** contains **JTextField enterField**, in which the user enters the URI of the file to read and **JEditorPane contentsArea** to display the contents of the file. When the user presses the *Enter* key in the **JTextField**, the program calls method **actionPerformed** (lines 34–37). Line 36 uses **ActionEvent** method **getActionCommand** to get the **String** the user input in the **JTextField** and passes that string to utility method **getThePage** (lines 73–95).

Lines 76–77 in method **getThePage** use method ***setCursor*** (inherited into class **JFrame** from class **Component**) to change the mouse cursor to the *wait cursor* (normally, an hourglass or a watch). If the file being downloaded is large, the wait cursor indicates to the user that the program is performing a task and that the user should wait for the task to complete. The **static Cursor** method ***getPredefinedCursor*** receives an integer indicating the cursor type (***Cursor.WAIT_CURSOR*** in this case). See the API documentation for class **Cursor** for a complete list of cursors.

Line 82 uses **JEditorPane** method ***setPage*** to download the document specified by **location** and display it in the **JEditorPane contents**. If there is an error downloading the document, method **setPage** throws an **IOException**. Also, if an invalid URL is specified, a **MalformedURLException** (a sublcass of **IOException**) occurs. If the document loads successfully, line 83 displays the current location in **enterField**.

Lines 93–94 sets the **Cursor** back to ***Cursor.DEFAULT_CURSOR*** (the default **Cursor**) to indicate that the document download is complete.

Typically, an HTML document contains *hyperlinks*—text, images or GUI components which, when clicked, provide quick access to another document on the Web. If a **JEditorPane** contains an HTML document and the user clicks a hyperlink, the **JEditorPane** generates a ***HyperlinkEvent*** (package **javax.swing.event**) and notifies all registered ***HyperlinkListener***s (package **javax.swing.event**) of that event. Lines 49–63 register a **HyperlinkListener** to handle **HyperlinkEvent**s. When a **HyperlinkEvent** occurs, the program calls method **hyperlinkUpdate** (lines 54–

59). Lines 56–57 use **HyperlinkEvent** method ***getEventType*** to determine the type of the **HyperlinkEvent**. Class **HyperlinkEvent** contains **public** inner class ***EventType*** that defines three hyperlink event types: ***ACTIVATED*** (the user clicked a hyperlink to change Web pages), ***ENTERED*** (the user moved the mouse over a hyperlink) and ***EXITED*** (the user moved the mouse away from a hyperlink). If a hyperlink was **ACTIVATED**, line 58 uses **HyperlinkEvent** method ***getURL*** to obtain the **URL** represented by the hyperlink. Method **toString** converts the returned **URL** to a **String** format that can be passed to utility method **getThePage**.

Software Engineering Observation 17.1

*A **JEditorPane** generates **HyperlinkEvent**s only if it is uneditable.*

17.4 Establishing a Simple Server Using Stream Sockets

The two examples discussed so far use high-level Java networking capabilities to communicate between applications. In those examples, it was not the Java programmer's responsibility to establish the connection between a client and a server. The first program relied on the Web browser to communicate with a Web server. The second program relied on a **JEditorPane** to perform the connection. This section begins our discussion of creating your own applications that can communicate with one another.

Establishing a simple server in Java requires five steps. Step 1 is to create a ***ServerSocket*** object. A call to the **ServerSocket** constructor such as

```
ServerSocket server = new ServerSocket( port, queueLength );
```

registers an available *port number* and specifies a maximum number of clients that can wait to connect to the server (i.e., the *queueLength*). The port number is used by clients to located the server application on the server computer. This often is called the *handshake point*. If the queue is full, the server refuses client connections. The preceding statement establishes the port where the server waits for connections from clients (a process known as *binding the server to the port*). Each client will ask to connect to the server on this *port*.

Programs manage each client connection with a ***Socket*** object. After binding the server to a port with a **ServerSocket** (Step 2), the server listens indefinitely (or *blocks*) for an attempt by a client to connect. To listen for a client, the program calls **ServerSocket** method **accept**, as in

```
Socket connection = server.accept();
```

This statement returns a **Socket** object when a connection with a client is established.

Step 3 is to get the **OutputStream** and **InputStream** objects that enable the server to communicate with the client by sending and receiving bytes. The server sends information to the client via an **OutputStream** object. The server receives information from the client via an **InputStream** object. To obtain the streams, the server invokes method **getOutputStream** on the **Socket** to get a reference to the **OutputStream** associated with the **Socket** and invokes method **getInputStream** on the **Socket** to get a reference to the **InputStream** associated with the **Socket**.

The **OutputStream** and **InputStream** objects can be used to send or receive individual bytes or sets of bytes with the **OutputStream** method **write** and the **InputStream** method **read**, respectively. Often it is useful to send or receive values of primitive

data types (such as **int** and **double**) or **Serializable** class data types (such as **String**) rather than sending bytes. In this case, we can use the techniques of Chapter 16 to *chain* other stream types (such as **ObjectOutputStream** and **ObjectInputStream**) to the **OutputStream** and **InputStream** associated with the **Socket**. For example,

```
ObjectInputStream input =
   new ObjectInputStream( connection.getInputStream() );

ObjectOutputStream output =
   new ObjectOutputStream( connection.getOutputStream() );
```

The beauty of establishing these relationships is that whatever the server writes to the **ObjectOutputStream** is sent via the **OutputStream** and is available at the client's **InputStream** and whatever the client writes to its **OutputStream** (with a corresponding **ObjectOutputStream**) is available via the server's **InputStream**.

Step 4 is the *processing* phase, in which the server and the client communicate via the **InputStream** and **OutputStream** objects. In Step 5, when the transmission is complete, the server closes the connection by invoking the **close** method on the **Socket** and on the corresponding streams.

Software Engineering Observation 17.2

With sockets, network I/O appears to Java programs to be identical to sequential file I/O. Sockets hide much of the complexity of network programming from the programmer.

Software Engineering Observation 17.3

With Java's multithreading, we can create multithreaded servers that can manage many simultaneous connections with many clients; this multithreaded-server architecture is precisely what popular network servers use.

Software Engineering Observation 17.4

*A multithreaded server can take the **Socket** returned by each call to **accept** and create a new thread that manages network I/O across that **Socket**, or a multithreaded server can maintain a pool of threads (a set of already existing threads) ready to manage network I/O across the new **Socket**s as they are created.*

Performance Tip 17.2

*In high-performance systems in which memory is abundant, a multithreaded server can be implemented to create a pool of threads that can be assigned quickly to handle network I/O across each new **Socket** as it is created. Thus, when the server receives a connection, the server need not incur the overhead of thread creation.*

17.5 Establishing a Simple Client Using Stream Sockets

Establishing a simple client in Java requires four steps. In Step 1, we create a **Socket** to connect to the server. The **Socket** constructor establishes the connection to the server. For example, the statement

```
Socket connection = new Socket( serverAddress, port );
```

uses the **Socket** constructor with two arguments—the server's Internet address (*serverAddress*) and the *port* number. If the connection attempt is successful, this statement returns

a **Socket**. A connection attempt that fails throws an instance of a subclass of **IOException**, so many programs simply catch **IOException**. An ***UnknownHostException*** occurs when a server address indicated by a client cannot be resolved. A ***ConnectException*** is thrown when an error occurs while attempting to connect to a server.

In Step 2, the client uses **Socket** methods **getInputStream** and **getOutputStream** to obtain references to the **Socket**'s **InputStream** and **OutputStream**. As we mentioned in the preceding section, often it is useful to send or receive values of primitive data types (such as **int** and **double**) or class data types (such as **String** and **Employee**) rather than sending bytes. If the server is sending information in the form of actual data types, the client should receive the information in the same format. Thus, if the server sends values with an **ObjectOutputStream**, the client should read those values with an **ObjectInputStream**.

Step 3 is the processing phase in which the client and the server communicate via the **InputStream** and **OutputStream** objects. In Step 4, the client closes the connection when the transmission is complete by invoking the **close** method on the **Socket** and the corresponding streams. When processing information sent by a server, the client must determine when the server is finished sending information so the client can call **close** to close the **Socket** connection. For example, the **InputStream** method **read** returns the value –1 when it detects end-of-stream (also called EOF—end-of-file). If an **ObjectInputStream** is used to read information from the server, an **EOFException** occurs when the client attempts to read a value from a stream on which end-of-stream is detected.

17.6 Client/Server Interaction with Stream Socket Connections

The applications of Fig. 17.4 and Fig. 17.5 use *stream sockets* to demonstrate a simple *client/server chat application*. The server waits for a client connection attempt. When a client application connects to the server, the server application sends a **String** object (remember that **String**s are **Serializable**) indicating that the connection was successful to the client. Then the client displays the message. Both the client and the server applications contain **JTextField**s, which allow the user to type a message and send it to the other application. When the client or the server sends the **String** "**TERMINATE**", the connection between the client and the server terminates. Then the server waits for the next client to connect. The definition of class **Server** appears in Fig. 17.4. The definition of class **Client** appears in Fig. 17.5. The screen captures showing the execution between the client and the server are shown as part of Fig. 17.5.

Class **Server**'s constructor (lines 25–58) creates the GUI of the application (a **JTextField** and a **JTextArea**). The **Server** object displays its output in a **JTextArea**. When the **main** method (lines 186–194) executes, it creates an instance of class **Server**, specifies the window's default close operation and calls method **runServer** (defined at lines 61–97).

Method **runServer** does the work of setting up the server to receive a connection and processing the connection when it occurs. The method creates a **ServerSocket** called **server** (line 68) to wait for connections. The **ServerSocket** is set up to listen for a connection from a client at port **5000**. The second argument to the constructor is the number of connections that can wait in a queue to connect to the server (**100** in this example). If the queue is full when a client attempts to connect, the server refuses the connection.

```
1  // Fig. 17.4: Server.java
2  // Set up a Server that will receive a connection
3  // from a client, send a string to the client,
4  // and close the connection.
5
6  // Java core packages
7  import java.io.*;
8  import java.net.*;
9  import java.awt.*;
10 import java.awt.event.*;
11
12 // Java extension packages
13 import javax.swing.*;
14
15 public class Server extends JFrame {
16    private JTextField enterField;
17    private JTextArea displayArea;
18    private ObjectOutputStream output;
19    private ObjectInputStream input;
20    private ServerSocket server;
21    private Socket connection;
22    private int counter = 1;
23
24    // set up GUI
25    public Server()
26    {
27       super( "Server" );
28
29       Container container = getContentPane();
30
31       // create enterField and register listener
32       enterField = new JTextField();
33       enterField.setEnabled( false );
34
35       enterField.addActionListener(
36
37          new ActionListener() {
38
39             // send message to client
40             public void actionPerformed( ActionEvent event )
41             {
42                sendData( event.getActionCommand() );
43             }
44
45          }  // end anonymous inner class
46
47       ); // end call to addActionListener
48
49       container.add( enterField, BorderLayout.NORTH );
50
51       // create displayArea
52       displayArea = new JTextArea();
```

Fig. 17.4 Server portion of a client/server stream-socket connection (part 1 of 4).

```
53          container.add( new JScrollPane( displayArea ),
54             BorderLayout.CENTER );
55
56          setSize( 300, 150 );
57          setVisible( true );
58       }
59
60       // set up and run server
61       public void runServer()
62       {
63          // set up server to receive connections;
64          // process connections
65          try {
66
67             // Step 1: Create a ServerSocket.
68             server = new ServerSocket( 5000, 100 );
69
70             while ( true ) {
71
72                // Step 2: Wait for a connection.
73                waitForConnection();
74
75                // Step 3: Get input and output streams.
76                getStreams();
77
78                // Step 4: Process connection.
79                processConnection();
80
81                // Step 5: Close connection.
82                closeConnection();
83
84                ++counter;
85             }
86          }
87
88          // process EOFException when client closes connection
89          catch ( EOFException eofException ) {
90             System.out.println( "Client terminated connection" );
91          }
92
93          // process problems with I/O
94          catch ( IOException ioException ) {
95             ioException.printStackTrace();
96          }
97       }
98
99       // wait for connection to arrive, then display connection info
100      private void waitForConnection() throws IOException
101      {
102         displayArea.setText( "Waiting for connection\n" );
103
104         // allow server to accept a connection
105         connection = server.accept();
```

Fig. 17.4 Server portion of a client/server stream-socket connection (part 2 of 4).

```
106
107         displayArea.append( "Connection " + counter +
108            " received from: " +
109            connection.getInetAddress().getHostName() );
110      }
111
112      // get streams to send and receive data
113      private void getStreams() throws IOException
114      {
115         // set up output stream for objects
116         output = new ObjectOutputStream(
117            connection.getOutputStream() );
118
119         // flush output buffer to send header information
120         output.flush();
121
122         // set up input stream for objects
123         input = new ObjectInputStream(
124            connection.getInputStream() );
125
126         displayArea.append( "\nGot I/O streams\n" );
127      }
128
129      // process connection with client
130      private void processConnection() throws IOException
131      {
132         // send connection successful message to client
133         String message = "SERVER>>> Connection successful";
134         output.writeObject( message );
135         output.flush();
136
137         // enable enterField so server user can send messages
138         enterField.setEnabled( true );
139
140         // process messages sent from client
141         do {
142
143            // read message and display it
144            try {
145               message = ( String ) input.readObject();
146               displayArea.append( "\n" + message );
147               displayArea.setCaretPosition(
148                  displayArea.getText().length() );
149            }
150
151            // catch problems reading from client
152            catch ( ClassNotFoundException classNotFoundException ) {
153               displayArea.append( "\nUnknown object type received" );
154            }
155
156         } while ( !message.equals( "CLIENT>>> TERMINATE" ) );
157      }
158
```

Fig. 17.4 Server portion of a client/server stream-socket connection (part 3 of 4).

```
159    // close streams and socket
160    private void closeConnection() throws IOException
161    {
162       displayArea.append( "\nUser terminated connection" );
163       enterField.setEnabled( false );
164       output.close();
165       input.close();
166       connection.close();
167    }
168
169    // send message to client
170    private void sendData( String message )
171    {
172       // send object to client
173       try {
174          output.writeObject( "SERVER>>> " + message );
175          output.flush();
176          displayArea.append( "\nSERVER>>>" + message );
177       }
178
179       // process problems sending object
180       catch ( IOException ioException ) {
181          displayArea.append( "\nError writing object" );
182       }
183    }
184
185    // execute application
186    public static void main( String args[] )
187    {
188       Server application = new Server();
189
190       application.setDefaultCloseOperation(
191          JFrame.EXIT_ON_CLOSE );
192
193       application.runServer();
194    }
195
196 }  // end class Server
```

Fig. 17.4 Server portion of a client/server stream-socket connection (part 4 of 4).

Software Engineering Observation 17.5

Port numbers can be between 0 and 65,535. Many operating systems reserve port numbers below 1024 for system services (such as e-mail and World Wide Web servers). Generally, these ports should not be specified as connection ports in user programs. In fact, some operating systems require special access privileges to use port numbers below 1024.

Line 73 calls method **`waitForConnection`** (lines 100–110) to wait for a client connection. After the connection is established, line 76 calls method **`getStreams`** (lines 113–127) to obtain references to the **`InputStream`** and **`OutputStream`** for the connection. Line 79 calls method **`processConnection`** to send the initial connection message to the client and to process all messages received from the client. Line 82 calls method **`closeConnection`** to terminate the connection with the client.

In method **waitForConnection** (lines 100–110), line 105 uses **ServerSocket** method **accept** to wait for a connection from a client and assigns the resulting **Socket** to **connection**. This method blocks until a connection is received (i.e., the thread in which **accept** is called stops executing until a client connects). Lines 107–109 output the host name of the computer that made the connection. **Socket** method **getInetAddress** returns an **InetAddress** object (package **java.net**) containing information about the client computer. **InetAddress** method ***getHostName*** returns the host name of the client computer. For example, if the Internet address of the computer is **127.0.0.1**, the corresponding host name would be **localhost**.

Method **getStreams** (lines 113–127) obtains references to the **InputStream** and **OutputStream** of the **Socket** and uses them to initialize an **ObjectInputStream** and an **ObjectOutputStream**, respectively. Notice the call to **ObjectOutputStream** method **flush** at line 120. This statement causes the **ObjectOutputStream** on the server to send a *stream header* to the corresponding client's **ObjectInputStream**. The stream header contains information such as the version of object serialization being used to send objects. This information is required by the **ObjectInputStream** so it can prepare to receive those objects correctly.

Software Engineering Observation 17.6

*When using an **ObjectOutputStream** and **ObjectInputStream** to send and receive objects over a network connection, always create the **ObjectOutputStream** first and **flush** the stream so the client's **ObjectInputStream** can prepare to receive the data. This is required only for applications that communicate using **ObjectOutputStream** and **ObjectInputStream**.*

Line 134 of method **processConnection** (lines 130–157) uses **ObjectOutputStream** method **writeObject** to send the string "**SERVER>>> Connection successful**" to the client. Line 135 flushes the output stream to ensure that the object is sent immediately; otherwise, the object could be held in an output buffer until more information is available to send.

Performance Tip 17.3

Output buffers typically are used to increase the efficiency of an application by sending larger amounts of data fewer times. The input and output components of a computer are typically much slower than the memory of the computer.

The **do/while** structure at lines 141–156 loops until the server receives the message "**CLIENT>>> TERMINATE**." Line 145 uses **ObjectInputStream** method **readObject** to read a **String** from the client. Line 146 displays the message in the **JTextArea**. Lines 147–148 use **JTextComponent** method ***setCaretPosition*** to position the input cursor in the **JTextArea** after the last character in the **JTextArea**. This scrolls the **JTextArea** as text is appended to it.

When the transmission is complete, method **processConnection** returns and the program calls method **closeConnection** (lines 160–167) to close the streams associated with the **Socket** and close the **Socket**. Next, the server waits for the next connection attempt from a client by continuing with line 73 at the beginning of the **while** loop.

When the user of the server application enters a **String** in the **JTextField** and presses the *Enter* key, the program calls method **actionPerformed** (lines 40–43), reads the **String** from the **JTextField** and calls utility method **sendData** (lines 170–183).

Method **sendData** sends the **String** object to the client, flushes the output buffer and appends the same **String** to the **JTextArea** in the server window.

Notice that the **Server** receives a connection, processes the connection, closes the connection and waits for the next connection. A more likely scenario would be a **Server** that receives a connection, sets up that connection to be processed as a separate thread of execution, and waits for new connections. The separate threads that process existing connections can continue to execute while the **Server** concentrates on new connection requests.

Like class **Server**, class **Client**'s (Fig. 17.5) constructor creates the GUI of the application (a **JTextField** and a **JTextArea**). The **Client** object displays its output in a **JTextArea**. When the **main** method (line 175–188) executes, it creates an instance of class **Client**, specifies the window's default close operation and calls method **runClient** (defined at lines 63–90). In this example, you can execute the client from any computer on the Internet and specify the Internet address or host name of the server computer as a command-line argument to the program. For example,

```
java Client 192.168.1.15
```

connects to the **Server** on the computer with Internet address **192.168.1.15**.

```
1  // Fig. 17.5: Client.java
2  // Set up a Client that will read information sent
3  // from a Server and display the information.
4
5  // Java core packages
6  import java.io.*;
7  import java.net.*;
8  import java.awt.*;
9  import java.awt.event.*;
10
11 // Java extension packages
12 import javax.swing.*;
13
14 public class Client extends JFrame {
15    private JTextField enterField;
16    private JTextArea displayArea;
17    private ObjectOutputStream output;
18    private ObjectInputStream input;
19    private String message = "";
20    private String chatServer;
21    private Socket client;
22
23    // initialize chatServer and set up GUI
24    public Client( String host )
25    {
26       super( "Client" );
27
28       // set server to which this client connects
29       chatServer = host;
```

Fig. 17.5 Demonstrating the client portion of a stream-socket connection between a client and a server (part 1 of 5).

```
30
31          Container container = getContentPane();
32
33          // create enterField and register listener
34          enterField = new JTextField();
35          enterField.setEnabled( false );
36
37          enterField.addActionListener(
38
39             new ActionListener() {
40
41                // send message to server
42                public void actionPerformed( ActionEvent event )
43                {
44                   sendData( event.getActionCommand() );
45                }
46
47             }  // end anonymous inner class
48
49          ); // end call to addActionListener
50
51          container.add( enterField, BorderLayout.NORTH );
52
53          // create displayArea
54          displayArea = new JTextArea();
55          container.add( new JScrollPane( displayArea ),
56             BorderLayout.CENTER );
57
58          setSize( 300, 150 );
59          setVisible( true );
60       }
61
62       // connect to server and process messages from server
63       public void runClient()
64       {
65          // connect to server, get streams, process connection
66          try {
67
68             // Step 1: Create a Socket to make connection
69             connectToServer();
70
71             // Step 2: Get the input and output streams
72             getStreams();
73
74             // Step 3: Process connection
75             processConnection();
76
77             // Step 4: Close connection
78             closeConnection();
79          }
80
```

Fig. 17.5 Demonstrating the client portion of a stream-socket connection between a client and a server (part 2 of 5).

```
81          // server closed connection
82          catch ( EOFException eofException ) {
83             System.out.println( "Server terminated connection" );
84          }
85
86          // process problems communicating with server
87          catch ( IOException ioException ) {
88             ioException.printStackTrace();
89          }
90       }
91
92       // get streams to send and receive data
93       private void getStreams() throws IOException
94       {
95          // set up output stream for objects
96          output = new ObjectOutputStream(
97             client.getOutputStream() );
98
99          // flush output buffer to send header information
100         output.flush();
101
102         // set up input stream for objects
103         input = new ObjectInputStream(
104            client.getInputStream() );
105
106         displayArea.append( "\nGot I/O streams\n" );
107      }
108
109      // connect to server
110      private void connectToServer() throws IOException
111      {
112         displayArea.setText( "Attempting connection\n" );
113
114         // create Socket to make connection to server
115         client = new Socket(
116            InetAddress.getByName( chatServer ), 5000 );
117
118         // display connection information
119         displayArea.append( "Connected to: " +
120            client.getInetAddress().getHostName() );
121      }
122
123      // process connection with server
124      private void processConnection() throws IOException
125      {
126         // enable enterField so client user can send messages
127         enterField.setEnabled( true );
128
129         // process messages sent from server
130         do {
131
```

Fig. 17.5 Demonstrating the client portion of a stream-socket connection between a client and a server (part 3 of 5).

```
132          // read message and display it
133          try {
134             message = ( String ) input.readObject();
135             displayArea.append( "\n" + message );
136             displayArea.setCaretPosition(
137                displayArea.getText().length() );
138          }
139
140          // catch problems reading from server
141          catch ( ClassNotFoundException classNotFoundException ) {
142            displayArea.append( "\nUnknown object type received" );
143          }
144
145       } while ( !message.equals( "SERVER>>> TERMINATE" ) );
146
147    }  // end method process connection
148
149    // close streams and socket
150    private void closeConnection() throws IOException
151    {
152       displayArea.append( "\nClosing connection" );
153       output.close();
154       input.close();
155       client.close();
156    }
157
158    // send message to server
159    private void sendData( String message )
160    {
161       // send object to server
162       try {
163          output.writeObject( "CLIENT>>> " + message );
164          output.flush();
165          displayArea.append( "\nCLIENT>>>" + message );
166       }
167
168       // process problems sending object
169       catch ( IOException ioException ) {
170          displayArea.append( "\nError writing object" );
171       }
172    }
173
174    // execute application
175    public static void main( String args[] )
176    {
177       Client application;
178
179       if ( args.length == 0 )
180          application = new Client( "127.0.0.1" );
181       else
182          application = new Client( args[ 0 ] );
183
```

Fig. 17.5 Demonstrating the client portion of a stream-socket connection between a client and a server (part 4 of 5).

```
184         application.setDefaultCloseOperation(
185            JFrame.EXIT_ON_CLOSE );
186
187         application.runClient();
188      }
189
190   }  // end class Client
```

The **Server** and **Client** windows after the **Client** connects to the **Server**

The **Server** and **Client** windows after the **Client** sends a message to the **Server**

The **Server** and **Client** windows after the **Server** sends a message to the **Client**

The **Server** and **Client** windows after the **Client** terminates the connection

Fig. 17.5 Demonstrating the client portion of a stream-socket connection between a client and a server (part 5 of 5).

Client method **runClient** (lines 63–90) performs the work necessary to connect to the **Server**, to receive data from the **Server** and to send data to the **Server**. Line 69 calls method **connectToServer** (lines 110–121) to perform the connection. After connecting, line 72 calls method **getStreams** (lines 93–107) to obtain references to the **Socket**'s **InputStream** and **OutputStream** objects. Then line 75 calls method **processConnection** (124–147) to handle messages sent from the server. When the connection terminates, line 78 calls **closeConnection** to close the streams and the **Socket**.

Method **connectToServer** (lines 110–121) creates a **Socket** called **client** (lines 115–116) to establish a connection. The method passes two arguments to the

Socket constructor—the Internet address of the server computer and the port number (5000) where that computer is awaiting client connections. The call to **InetAddress** **static** method **getByName** in the first argument returns an **InetAddress** object containing the Internet address specified as a command-line argument to the application (or **127.0.0.1** if no command-line arguments are specified). Method **getByName** can receive a **String** containing either the actual Internet address or the host name of the server. The first argument also could have been written other ways. For the localhost address 127.0.0.1, the first argument could be

```
InetAddress.getByName( "localhost" )
```

or

```
InetAddress.getLocalHost()
```

Also, there are versions of the **Socket** constructor that receive a **String** for the Internet address or host name. The first argument could have been specified as **"127.0.0.1"** or **"localhost"**. [*Note*: We chose to demonstrate the client/server relationship by connecting between programs executing on the same computer (**localhost**). Normally, this first argument would be the Internet address of another computer. The **InetAddress** object for another computer can be obtained by specifying the Internet address or host name of the other computer as the **String** argument to **InetAddress.getByName**.]

The **Socket** constructor's second argument is the server port number. This number must match the port number at which the server is waiting for connections (called the handshake point). Once the connection is made, a message is displayed in the **JTextArea** (lines 119–120) indicating the name of the server computer to which the client connected.

The **Client** uses an **ObjectOutputStream** to send data to the server and an **ObjectInputStream** to receive data from the server. Method **getStreams** (lines 93–107) creates the **ObjectOutputStream** and **ObjectInputStream** objects that use the **OutputStream** and **InputStream** objects associated with **client**.

Method **processConnection** (lines 124–147) contains a **do/while** structure that loops until the client receives the message "**SERVER>>> TERMINATE**." Line 134 uses **ObjectInputStream** method **readObject** to read a **String** from the server. Line 135 displays the message in the **JTextArea**. Lines 136–137 use **JTextComponent** method **setCaretPosition** to position the input cursor in the **JTextArea** after the last character in the **JTextArea**.

When the transmission is complete, method **closeConnection** (lines 150–156) closes the streams and the **Socket**.

When the user of the client application enters a **String** in the **JTextField** and presses the *Enter* key, the program calls method **actionPerformed** (lines 42–45) to read the **String** from the **JTextField** and invoke utility method **sendData** (159–172). Method **sendData** sends the **String** object to server client, flushes the output buffer and appends the same **String** to the **JTextArea** in the client window.

17.7 Connectionless Client/Server Interaction with Datagrams

We have been discussing *connection-oriented, streams-based transmission*. Now we consider *connectionless transmission with datagrams*.

Connection-oriented transmission is like the telephone system in which you dial and are given a *connection* to the telephone of the person with whom you wish to communicate. The connection is maintained for the duration of your phone call, even when you are not talking.

Connectionless transmission with *datagrams* is more like the way mail is carried via the postal service. If a large message will not fit in one envelope, you break it into separate message pieces that you place in separate, sequentially numbered envelopes. Each of the letters is then mailed at the same time. The letters could arrive in order, out of order or not at all (although the last case is rare, it does happen). The person at the receiving end reassembles the message pieces into sequential order before attempting to make sense of the message. If your message is small enough to fit in one envelope, you do not have to worry about the "out-of-sequence" problem, but it is still possible that your message might not arrive. One difference between datagrams and postal mail is that duplicates of datagrams can arrive on the receiving computer.

The programs of Fig. 17.6 and Fig. 17.7 use datagrams to send packets of information between a client application and a server application. In the **`Client`** application (Fig. 17.7), the user types a message into a **`JTextField`** and presses *Enter*. The program converts the message into a **`byte`** array and places it in a datagram packet that is sent to the server. The **`Server`** (Fig. 17.6) receives the packet and displays the information in the packet, then *echoes* the packet back to the client. When the client receives the packet, the client displays the information in the packet. In this example, the **`Client`** and **`Server`** classes are implemented similarly.

Class **`Server`** (Fig. 17.6) defines two **`DatagramPacket`**s that the server uses to send and receive information and one **`DatagramSocket`** that sends and receives these packets. The constructor for class **`Server`** (lines 20–41) creates the graphical user interface where the packets of information will be displayed. Next the constructor creates the **`DatagramSocket`** in a **`try`** block. Line 32 uses the **`DatagramSocket`** constructor that takes an integer port number argument (**`5000`**) to bind the server to a port where the server can receive packets from clients. **`Client`**s sending packets to this **`Server`** specify port **`5000`** in the packets they send. The **`DatagramSocket`** constructor throws a ***`SocketException`*** if it fails to bind the **`DatagramSocket`** to a port.

Common Programming Error 17.2

Specifying a port that is already in use or specifying an invalid port number when creating a ***`DatagramSocket`*** *results in a* ***`BindException`***.

```
1  // Fig. 17.6: Server.java
2  // Set up a Server that will receive packets from a
3  // client and send packets to a client.
4
5  // Java core packages
6  import java.io.*;
7  import java.net.*;
8  import java.awt.*;
9  import java.awt.event.*;
10
```

Fig. 17.6 Demonstrating the server side of connectionless client/server computing with datagrams (part 1 of 4).

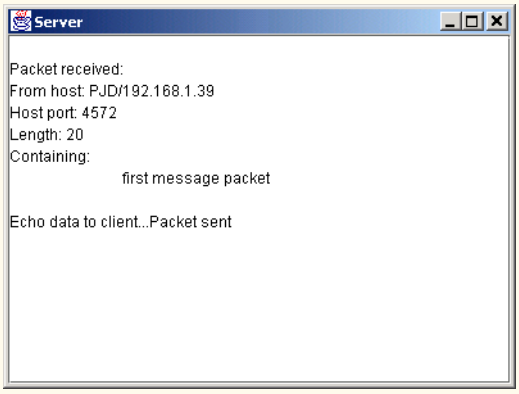
```
11  // Java extension packages
12  import javax.swing.*;
13
14  public class Server extends JFrame {
15     private JTextArea displayArea;
16     private DatagramPacket sendPacket, receivePacket;
17     private DatagramSocket socket;
18
19     // set up GUI and DatagramSocket
20     public Server()
21     {
22        super( "Server" );
23
24        displayArea = new JTextArea();
25        getContentPane().add( new JScrollPane( displayArea ),
26           BorderLayout.CENTER );
27        setSize( 400, 300 );
28        setVisible( true );
29
30        // create DatagramSocket for sending and receiving packets
31        try {
32           socket = new DatagramSocket( 5000 );
33        }
34
35        // process problems creating DatagramSocket
36        catch( SocketException socketException ) {
37           socketException.printStackTrace();
38           System.exit( 1 );
39        }
40
41     }  // end Server constructor
42
43     // wait for packets to arrive, then display data and echo
44     // packet to client
45     public void waitForPackets()
46     {
47        // loop forever
48        while ( true ) {
49
50           // receive packet, display contents, echo to client
51           try {
52
53              // set up packet
54              byte data[] = new byte[ 100 ];
55              receivePacket =
56                 new DatagramPacket( data, data.length );
57
58              // wait for packet
59              socket.receive( receivePacket );
60
61              // process packet
62              displayPacket();
```

Fig. 17.6 Demonstrating the server side of connectionless client/server computing with datagrams (part 2 of 4).

```
63
64             // echo information from packet back to client
65             sendPacketToClient();
66          }
67
68          // process problems manipulating packet
69          catch( IOException ioException ) {
70             displayArea.append( ioException.toString() + "\n" );
71             ioException.printStackTrace();
72          }
73
74       }  // end while
75
76    }  // end method waitForPackets
77
78    // display packet contents
79    private void displayPacket()
80    {
81       displayArea.append( "\nPacket received:" +
82          "\nFrom host: " + receivePacket.getAddress() +
83          "\nHost port: " + receivePacket.getPort() +
84          "\nLength: " + receivePacket.getLength() +
85          "\nContaining:\n\t" +
86          new String( receivePacket.getData(), 0,
87             receivePacket.getLength() ) );
88    }
89
90    // echo packet to client
91    private void sendPacketToClient() throws IOException
92    {
93       displayArea.append( "\n\nEcho data to client..." );
94
95       // create packet to send
96       sendPacket = new DatagramPacket( receivePacket.getData(),
97          receivePacket.getLength(), receivePacket.getAddress(),
98          receivePacket.getPort() );
99
100      // send packet
101      socket.send( sendPacket );
102
103      displayArea.append( "Packet sent\n" );
104      displayArea.setCaretPosition(
105         displayArea.getText().length() );
106   }
107
108   // execute application
109   public static void main( String args[] )
110   {
111      Server application = new Server();
112
113      application.setDefaultCloseOperation(
114         JFrame.EXIT_ON_CLOSE );
```

Fig. 17.6 Demonstrating the server side of connectionless client/server computing with datagrams (part 3 of 4).

```
115
116        application.waitForPackets();
117     }
118
119  }  // end class Server
```



The **Server** window after the client sends a packet of data

Fig. 17.6 Demonstrating the server side of connectionless client/server computing with datagrams (part 4 of 4).

Server method **waitForPackets** (lines 45–76) uses an infinite loop to wait for packets to arrive at the **Server**. Lines 54–56 create a **DatagramPacket** in which a received packet of information can be stored. The **DatagramPacket** constructor for this purpose receives two arguments—a **byte** array containing the data and the length of the **byte** array. Line 59 waits for a packet to arrive at the **Server**. Method ***receive*** blocks until a packet arrives, then stores the packet in its **DatagramPacket** argument. Method **receive** throws an **IOException** if an error occurs receiving a packet.

When a packet arrives, the program calls method **displayPacket** (lines 79–88) to append the packet's contents to **displayArea**. **DatagramPacket** method ***getAddress*** (line 82) returns an **InetAddress** object containing the host name of the computer from which the packet was sent. Method ***getPort*** (line 83) returns an integer specifying the port number through which the host computer sent the packet. Method ***getLength*** (line 84) returns an integer representing the number of bytes of data that were sent. Method ***getData*** (line 86) returns a **byte** array containing the data that was sent. The program uses the **byte** array to initialize a **String** object so the data can be output to the **JTextArea**.

After displaying a packet, the program calls method **sendPacketToClient** (line 65) to create a new packet and send it to the client. Lines 96–98 create **sendPacket** and pass four arguments to the **DatagramPacket** constructor. The first argument specifies the **byte** array to send. The second argument specifies the number of bytes to send. The third argument specifies the client computer's Internet address, to which the packet will be sent. The fourth argument specifies the port where the client is waiting to receive packets. Line 101 sends the packet over the network. Method ***send*** throws an **IOException** if an error occurs sending a packet.

Class **Client** (Fig. 17.7) works similarly to class **Server**, except that the **Client** sends packets only when the user types a message in a **JTextField** and presses the *Enter*

key. When this occurs, the program calls method **actionPerformed** (lines 34–67), which converts the **String** the user entered in the **JTextField** into a **byte** array (line 45). Lines 48–50 create a **DatagramPacket** and initialize it with the **byte** array, the length of the **String** that was entered by the user, the Internet address to which the packet is to be sent (**InetAddress.getLocalHost()** in this example) and the port number at which the **Server** is waiting for packets. Line 53 sends the packet. Note that the client in this example must know that the server is receiving packets at port 5000; otherwise, the server will not receive the packets.

```
1  // Fig. 17.7: Client.java
2  // Set up a Client that will send packets to a
3  // server and receive packets from a server.
4
5  // Java core packages
6  import java.io.*;
7  import java.net.*;
8  import java.awt.*;
9  import java.awt.event.*;
10
11 // Java extension packages
12 import javax.swing.*;
13
14 public class Client extends JFrame {
15    private JTextField enterField;
16    private JTextArea displayArea;
17    private DatagramPacket sendPacket, receivePacket;
18    private DatagramSocket socket;
19
20    // set up GUI and DatagramSocket
21    public Client()
22    {
23       super( "Client" );
24
25       Container container = getContentPane();
26
27       enterField = new JTextField( "Type message here" );
28
29       enterField.addActionListener(
30
31          new ActionListener() {
32
33             // create and send a packet
34             public void actionPerformed( ActionEvent event )
35             {
36                // create and send packet
37                try {
38                   displayArea.append(
39                      "\nSending packet containing: " +
40                      event.getActionCommand() + "\n" );
41
```

Fig. 17.7 Demonstrating the client side of connectionless client/server computing with datagrams (part 1 of 4).

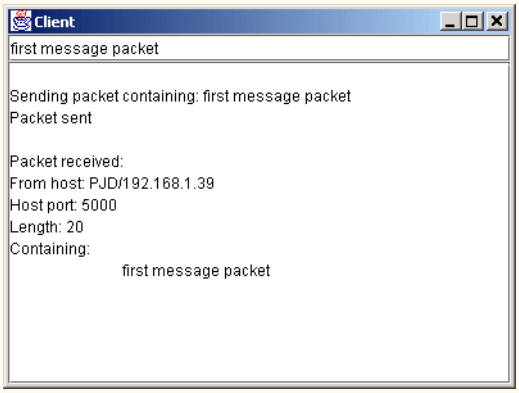
```
42                    // get message from textfield and convert to
43                    // array of bytes
44                    String message = event.getActionCommand();
45                    byte data[] = message.getBytes();
46
47                    // create sendPacket
48                    sendPacket = new DatagramPacket(
49                       data, data.length,
50                       InetAddress.getLocalHost(), 5000 );
51
52                    // send packet
53                    socket.send( sendPacket );
54
55                    displayArea.append( "Packet sent\n" );
56                    displayArea.setCaretPosition(
57                       displayArea.getText().length() );
58                 }
59
60                 // process problems creating or sending packet
61                 catch ( IOException ioException ) {
62                    displayArea.append(
63                       ioException.toString() + "\n" );
64                    ioException.printStackTrace();
65                 }
66
67              }  // end actionPerformed
68
69           }  // end anonymous inner class
70
71        ); // end call to addActionListener
72
73        container.add( enterField, BorderLayout.NORTH );
74
75        displayArea = new JTextArea();
76        container.add( new JScrollPane( displayArea ),
77           BorderLayout.CENTER );
78
79        setSize( 400, 300 );
80        setVisible( true );
81
82        // create DatagramSocket for sending and receiving packets
83        try {
84           socket = new DatagramSocket();
85        }
86
87        // catch problems creating DatagramSocket
88        catch( SocketException socketException ) {
89           socketException.printStackTrace();
90           System.exit( 1 );
91        }
92
93     }  // end Client constructor
```

Fig. 17.7 Demonstrating the client side of connectionless client/server computing with datagrams (part 2 of 4).

```
94
95       // wait for packets to arrive from Server,
96       // then display packet contents
97       public void waitForPackets()
98       {
99          // loop forever
100         while ( true ) {
101
102            // receive packet and display contents
103            try {
104
105               // set up packet
106               byte data[] = new byte[ 100 ];
107               receivePacket =
108                  new DatagramPacket( data, data.length );
109
110               // wait for packet
111               socket.receive( receivePacket );
112
113               // display packet contents
114               displayPacket();
115            }
116
117            // process problems receiving or displaying packet
118            catch( IOException exception ) {
119               displayArea.append( exception.toString() + "\n" );
120               exception.printStackTrace();
121            }
122
123         }  // end while
124
125      }  // end method waitForPackets
126
127      // display contents of receivePacket
128      private void displayPacket()
129      {
130         displayArea.append( "\nPacket received:" +
131            "\nFrom host: " + receivePacket.getAddress() +
132            "\nHost port: " + receivePacket.getPort() +
133            "\nLength: " + receivePacket.getLength() +
134            "\nContaining:\n\t" +
135            new String( receivePacket.getData(), 0,
136               receivePacket.getLength() ) );
137
138         displayArea.setCaretPosition(
139            displayArea.getText().length() );
140      }
141
142      // execute application
143      public static void main( String args[] )
144      {
145         Client application = new Client();
```

Fig. 17.7 Demonstrating the client side of connectionless client/server computing with datagrams (part 3 of 4).

```
146
147         application.setDefaultCloseOperation(
148            JFrame.EXIT_ON_CLOSE );
149
150         application.waitForPackets();
151      }
152
153   }  // end class Client
```



The **Client** window after sending a packet to the server and receiving the packet back from the server

Fig. 17.7 Demonstrating the client side of connectionless client/server computing with datagrams (part 4 of 4).

Notice that the **DatagramSocket** constructor call (line 84) in this application does not specify any arguments. This constructor allows the computer to select the next available port number for the **DatagramSocket**. The client does not need a specific port number, because the server receives the client's port number as part of each **DatagramPacket** sent by the client. Thus, the server can send packets back to the same computer and port number from which the server receives a packet of information.

Client method **waitForPackets** (lines 97–125) uses an infinite loop to wait for packets from the server. Line 111 blocks until a packet arrives. Note that this does not prevent the user from sending a packet, because the GUI events are handled in the event dispatch thread. It only prevents the **while** loop from continuing until a packet arrives at the **Client**. When a packet arrives, line 111 stores the packet in **receivePacket**, and line 114 calls method **displayPacket** (128–140) to display the packet's contents in the **JTextArea**.

17.8 Client/Server Tic-Tac-Toe Using a Multithreaded Server

In this section, we present the popular game Tic-Tac-Toe implemented by using client/server techniques with stream sockets. The program consists of a **TicTacToeServer** application (Fig. 17.8) that allows two **TicTacToeClient** applets (Fig. 17.9) to connect to the server and play Tic-Tac-Toe (outputs shown in Fig. 17.10). As the server receives each client connection, it creates an instance of inner class **Player** (lines 158–279 of Fig. 17.8) to process the client in a separate thread. These threads enable the clients to play the game independently. The server assigns Xs to the first client to connect (X makes the first move) and assigns

Os to the second client to connect. The server maintains the information about the board so it can determine whether a player's move is a valid or invalid move. Each **TicTacToeClient** applet (Fig. 17.9) maintains its own GUI version of the Tic-Tac-Toe board on which it displays the state of the game. The clients can place a mark only in an empty square on the board. Class **Square** (lines 212–270 of Fig. 17.9) implements each of the nine squares on the board. Class **TicTacToeServer** and class **Player** are implemented in file **TicTacToeServer.java** (Fig. 17.8). Class **TicTacToeClient** and class **Square** are implemented in file **TicTacToeClient.java** (Fig. 17.9).

```
1  // Fig. 17.8: TicTacToeServer.java
2  // This class maintains a game of Tic-Tac-Toe for two
3  // client applets.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.net.*;
9  import java.io.*;
10
11 // Java extension packages
12 import javax.swing.*;
13
14 public class TicTacToeServer extends JFrame {
15    private byte board[];
16    private JTextArea outputArea;
17    private Player players[];
18    private ServerSocket server;
19    private int currentPlayer;
20
21    // set up tic-tac-toe server and GUI that displays messages
22    public TicTacToeServer()
23    {
24       super( "Tic-Tac-Toe Server" );
25
26       board = new byte[ 9 ];
27       players = new Player[ 2 ];
28       currentPlayer = 0;
29
30       // set up ServerSocket
31       try {
32          server = new ServerSocket( 5000, 2 );
33       }
34
35       // process problems creating ServerSocket
36       catch( IOException ioException ) {
37          ioException.printStackTrace();
38          System.exit( 1 );
39       }
40
41       // set up JTextArea to display messages during execution
42       outputArea = new JTextArea();
```

Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 1 of 6).

```
43          getContentPane().add( outputArea, BorderLayout.CENTER );
44          outputArea.setText( "Server awaiting connections\n" );
45
46          setSize( 300, 300 );
47          setVisible( true );
48       }
49
50       // wait for two connections so game can be played
51       public void execute()
52       {
53          // wait for each client to connect
54          for ( int i = 0; i < players.length; i++ ) {
55
56             // wait for connection, create Player, start thread
57             try {
58                players[ i ] = new Player( server.accept(), i );
59                players[ i ].start();
60             }
61
62             // process problems receiving connection from client
63             catch( IOException ioException ) {
64                ioException.printStackTrace();
65                System.exit( 1 );
66             }
67          }
68
69          // Player X is suspended until Player O connects.
70          // Resume player X now.
71          synchronized ( players[ 0 ] ) {
72             players[ 0 ].setSuspended( false );
73             players[ 0 ].notify();
74          }
75
76       }  // end method execute
77
78       // display a message in outputArea
79       public void display( String message )
80       {
81          outputArea.append( message + "\n" );
82       }
83
84       // Determine if a move is valid.
85       // This method is synchronized because only one move can be
86       // made at a time.
87       public synchronized boolean validMove(
88          int location, int player )
89       {
90          boolean moveDone = false;
91
92          // while not current player, must wait for turn
93          while ( player != currentPlayer ) {
94
```

Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 2 of 6).

```
95            // wait for turn
96            try {
97               wait();
98            }
99
100           // catch wait interruptions
101           catch( InterruptedException interruptedException ) {
102              interruptedException.printStackTrace();
103           }
104        }
105
106        // if location not occupied, make move
107        if ( !isOccupied( location ) ) {
108
109           // set move in board array
110           board[ location ] =
111              ( byte ) ( currentPlayer == 0 ? 'X' : 'O' );
112
113           // change current player
114           currentPlayer = ( currentPlayer + 1 ) % 2;
115
116           // let new current player know that move occurred
117           players[ currentPlayer ].otherPlayerMoved( location );
118
119           // tell waiting player to continue
120           notify();
121
122           // tell player that made move that the move was valid
123           return true;
124        }
125
126        // tell player that made move that the move was not valid
127        else
128           return false;
129     }
130
131     // determine whether location is occupied
132     public boolean isOccupied( int location )
133     {
134        if ( board[ location ] == 'X' || board [ location ] == 'O' )
135            return true;
136        else
137            return false;
138     }
139
140     // place code in this method to determine whether game over
141     public boolean gameOver()
142     {
143        return false;
144     }
145
```

Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 3 of 6).

```
146    // execute application
147    public static void main( String args[] )
148    {
149       TicTacToeServer application = new TicTacToeServer();
150
151       application.setDefaultCloseOperation(
152          JFrame.EXIT_ON_CLOSE );
153
154       application.execute();
155    }
156
157    // private inner class Player manages each Player as a thread
158    private class Player extends Thread {
159       private Socket connection;
160       private DataInputStream input;
161       private DataOutputStream output;
162       private int playerNumber;
163       private char mark;
164       protected boolean suspended = true;
165
166       // set up Player thread
167       public Player( Socket socket, int number )
168       {
169          playerNumber = number;
170
171          // specify player's mark
172          mark = ( playerNumber == 0 ? 'X' : 'O' );
173
174          connection = socket;
175
176          // obtain streams from Socket
177          try {
178             input = new DataInputStream(
179                connection.getInputStream() );
180             output = new DataOutputStream(
181                connection.getOutputStream() );
182          }
183
184          // process problems getting streams
185          catch( IOException ioException ) {
186             ioException.printStackTrace();
187             System.exit( 1 );
188          }
189       }
190
191       // send message that other player moved; message contains
192       // a String followed by an int
193       public void otherPlayerMoved( int location )
194       {
195          // send message indicating move
196          try {
197             output.writeUTF( "Opponent moved" );
```

Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 4 of 6).

```
198             output.writeInt( location );
199          }
200
201          // process problems sending message
202          catch ( IOException ioException ) {
203             ioException.printStackTrace();
204          }
205       }
206
207       // control thread's execution
208       public void run()
209       {
210          // send client message indicating its mark (X or O),
211          // process messages from client
212          try {
213             display( "Player " + ( playerNumber == 0 ?
214               'X' : 'O' ) + " connected" );
215
216             // send player's mark
217             output.writeChar( mark );
218
219             // send message indicating connection
220             output.writeUTF( "Player " +
221                ( playerNumber == 0 ? "X connected\n" :
222                   "O connected, please wait\n" ) );
223
224             // if player X, wait for another player to arrive
225             if ( mark == 'X' ) {
226                output.writeUTF( "Waiting for another player" );
227
228                // wait for player O
229                try {
230                   synchronized( this ) {
231                      while ( suspended )
232                         wait();
233                   }
234                }
235
236                // process interruptions while waiting
237                catch ( InterruptedException exception ) {
238                   exception.printStackTrace();
239                }
240
241                // send message that other player connected and
242                // player X can make a move
243                output.writeUTF(
244                   "Other player connected. Your move." );
245             }
246
247             // while game not over
248             while ( ! gameOver() ) {
249
```

Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 5 of 6).

```
250                // get move location from client
251                int location = input.readInt();
252
253                // check for valid move
254                if ( validMove( location, playerNumber ) ) {
255                   display( "loc: " + location );
256                   output.writeUTF( "Valid move." );
257                }
258                else
259                   output.writeUTF( "Invalid move, try again" );
260             }
261
262             // close connection to client
263             connection.close();
264          }
265
266          // process problems communicating with client
267          catch( IOException ioException ) {
268             ioException.printStackTrace();
269             System.exit( 1 );
270          }
271       }
272
273       // set whether or not thread is suspended
274       public void setSuspended( boolean status )
275       {
276          suspended = status;
277       }
278
279    }  // end class Player
280
281 }  // end class TicTacToeServer
```

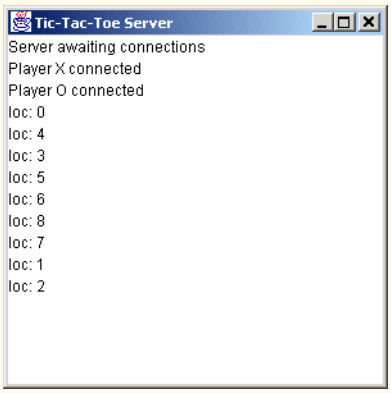


Fig. 17.8 Server side of client/server Tic-Tac-Toe program (part 6 of 6).

We begin with a discussion of the server side of the Tic-Tac-Toe game. When the **TicTacToeServer** application executes, the **main** method (lines 147–155) creates a **TicTacToeServer** object called **application**. The constructor (lines 22–48) attempts to set up a **ServerSocket**. If successful, the program displays the server

window, and **main** invokes the **TicTacToeServer** method **execute** (lines 51–76). Method **execute** loops twice, blocking at line 58 each time while waiting for a client connection. When a client connects, line 58 creates a new **Player** object to manage the connection as a separate thread, and line 59 calls that object's **start** method to begin executing the thread.

When the **TicTacToeServer** creates a **Player**, the **Player** constructor (lines 167–189) receives the **Socket** object representing the connection to the client and gets the associated input and output streams. The **Player**'s **run** method (lines 208–271) controls the information that is sent to the client and the information that is received from the client. First, it tells the client that the client's connection has been made (lines 213–214), then it passes to the client the character that the client will place on the board when a move is made (line 217). Lines 230–233 suspend each **Player** thread as it starts executing, because neither player is allowed to make a move when it first connects. Player X can move only when player O connects, and player O can make a move only after player X.

At this point, the game can be played, and the **run** method begins executing its **while** structure (lines 248–260). Each iteration of this **while** structure reads an integer (line 253) representing the location where the client wants to place a mark, and line 254 invokes the **TicTacToeServer** method **validMove** (lines 87–129) to check the move. Lines 254–259 send a message to the client indicating whether the move was valid. The program maintains board locations as numbers from 0 to 8 (0 through 2 for the first row, 3 through 5 for the second row and 6 through 8 for the third row).

Method **validMove** (lines 87–129 in class **TicTacToeServer**) is a **synchronized** method that allows only one player at a time to move. Synchronizing **validMove** prevents both players from modifying the state information of the game simultaneously. If the **Player** attempting to validate a move is not the current player (i.e., the one allowed to make a move), the **Player** is placed in a *wait* state until it is that **Player**'s turn to move. If the position for the move being validated is already occupied on the board, **validMove** returns **false**. Otherwise, the server places a mark for the player in its local representation of the board (lines 110–111), notifies the other **Player** object (line 117) that a move has been made (so the client can be sent a message), invokes method **notify** (line 120) so the waiting **Player** (if there is one) can validate a move and returns **true** (line 123) to indicate that the move is valid.

When a **TicTacToeClient** (Fig. 17.9) applet begins execution, it creates a **JTextArea** in which messages from the server and a representation of the board using nine **Square** objects are displayed. The applet's **start** method (lines 80–104) opens a connection to the server and gets the associated input and output streams from the **Socket** object. Class **TicTacToeClient** implements interface **Runnable** so that a separate thread can read messages from the server. This approach enables the user to interact with the board (in the event-dispatch thread) while waiting for messages from the server. After establishing the connection to the server, line 102 creates **Thread** object **outputThread** and initializes it with the **Runnable** applet, then line 103 calls the thread's **start** method. The applet's **run** method (lines 108–137) controls the separate thread of execution. The method first reads the mark character (X or O) from the server (line 112), then loops continually (lines 123–135) and reads messages from the server (line 127). Each message is passed to the applet's **processMessage** method (lines 140–211) for processing.

```
1  // Fig. 17.9: TicTacToeClient.java
2  // Client for the TicTacToe program
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.net.*;
8  import java.io.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 // Client class to let a user play Tic-Tac-Toe with
14 // another user across a network.
15 public class TicTacToeClient extends JApplet
16    implements Runnable {
17
18    private JTextField idField;
19    private JTextArea displayArea;
20    private JPanel boardPanel, panel2;
21    private Square board[][], currentSquare;
22    private Socket connection;
23    private DataInputStream input;
24    private DataOutputStream output;
25    private Thread outputThread;
26    private char myMark;
27    private boolean myTurn;
28
29    // Set up user-interface and board
30    public void init()
31    {
32       Container container = getContentPane();
33
34       // set up JTextArea to display messages to user
35       displayArea = new JTextArea( 4, 30 );
36       displayArea.setEditable( false );
37       container.add( new JScrollPane( displayArea ),
38          BorderLayout.SOUTH );
39
40       // set up panel for squares in board
41       boardPanel = new JPanel();
42       boardPanel.setLayout( new GridLayout( 3, 3, 0, 0 ) );
43
44       // create board
45       board = new Square[ 3 ][ 3 ];
46
47       // When creating a Square, the location argument to the
48       // constructor is a value from 0 to 8 indicating the
49       // position of the Square on the board. Values 0, 1,
50       // and 2 are the first row, values 3, 4, and 5 are the
51       // second row. Values 6, 7, and 8 are the third row.
52       for ( int row = 0; row < board.length; row++ ) {
53
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 1 of 6).

```
54             for ( int column = 0;
55                       column < board[ row ].length; column++ ) {
56
57                // create Square
58                board[ row ][ column ] =
59                   new Square( ' ', row * 3 + column );
60
61                boardPanel.add( board[ row ][ column ] );
62             }
63
64          }
65
66          // textfield to display player's mark
67          idField = new JTextField();
68          idField.setEditable( false );
69          container.add( idField, BorderLayout.NORTH );
70
71          // set up panel to contain boardPanel (for layout purposes)
72          panel2 = new JPanel();
73          panel2.add( boardPanel, BorderLayout.CENTER );
74          container.add( panel2, BorderLayout.CENTER );
75       }
76
77       // Make connection to server and get associated streams.
78       // Start separate thread to allow this applet to
79       // continually update its output in text area display.
80       public void start()
81       {
82          // connect to server, get streams and start outputThread
83          try {
84
85             // make connection
86             connection = new Socket(
87                InetAddress.getByName( "127.0.0.1" ), 5000 );
88
89             // get streams
90             input = new DataInputStream(
91                connection.getInputStream() );
92             output = new DataOutputStream(
93                connection.getOutputStream() );
94          }
95
96          // catch problems setting up connection and streams
97          catch ( IOException ioException ) {
98             ioException.printStackTrace();
99          }
100
101         // create and start output thread
102         outputThread = new Thread( this );
103         outputThread.start();
104      }
105
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 2 of 6).

```
106    // control thread that allows continuous update of the
107    // text area displayArea
108    public void run()
109    {
110       // get player's mark (X or O)
111       try {
112          myMark = input.readChar();
113          idField.setText( "You are player \"" + myMark + "\"" );
114          myTurn = ( myMark == 'X' ? true : false );
115       }
116
117       // process problems communicating with server
118       catch ( IOException ioException ) {
119          ioException.printStackTrace();
120       }
121
122       // receive messages sent to client and output them
123       while ( true ) {
124
125          // read message from server and process message
126          try {
127             String message = input.readUTF();
128             processMessage( message );
129          }
130
131          // process problems communicating with server
132          catch ( IOException ioException ) {
133             ioException.printStackTrace();
134          }
135       }
136
137    }  // end method run
138
139    // process messages received by client
140    public void processMessage( String message )
141    {
142       // valid move occurred
143       if ( message.equals( "Valid move." ) ) {
144          displayArea.append( "Valid move, please wait.\n" );
145
146          // set mark in square from event-dispatch thread
147          SwingUtilities.invokeLater(
148
149             new Runnable() {
150
151                public void run()
152                {
153                   currentSquare.setMark( myMark );
154                }
155
156             }
157
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 3 of 6).

```
158            ); // end call to invokeLater
159         }
160
161         // invalid move occurred
162         else if ( message.equals( "Invalid move, try again" ) ) {
163            displayArea.append( message + "\n" );
164            myTurn = true;
165         }
166
167         // opponent moved
168         else if ( message.equals( "Opponent moved" ) ) {
169
170            // get move location and update board
171            try {
172               final int location = input.readInt();
173
174               // set mark in square from event-dispatch thread
175               SwingUtilities.invokeLater(
176
177                  new Runnable() {
178
179                     public void run()
180                     {
181                        int row = location / 3;
182                        int column = location % 3;
183
184                        board[ row ][ column ].setMark(
185                           ( myMark == 'X' ? 'O' : 'X' ) );
186                        displayArea.append(
187                           "Opponent moved. Your turn.\n" );
188                     }
189
190                  }
191
192               ); // end call to invokeLater
193
194               myTurn = true;
195            }
196
197            // process problems communicating with server
198            catch ( IOException ioException ) {
199               ioException.printStackTrace();
200            }
201
202         }
203
204         // simply display message
205         else
206            displayArea.append( message + "\n" );
207
208         displayArea.setCaretPosition(
209            displayArea.getText().length() );
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 4 of 6).

```
210
211    }  // end method processMessage
212
213    // send message to server indicating clicked square
214    public void sendClickedSquare( int location )
215    {
216       if ( myTurn ) {
217
218          // send location to server
219          try {
220             output.writeInt( location );
221             myTurn = false;
222          }
223
224          // process problems communicating with server
225          catch ( IOException ioException ) {
226             ioException.printStackTrace();
227          }
228       }
229    }
230
231    // set current Square
232    public void setCurrentSquare( Square square )
233    {
234       currentSquare = square;
235    }
236
237    // private class for the sqaures on the board
238    private class Square extends JPanel {
239       private char mark;
240       private int location;
241
242       public Square( char squareMark, int squareLocation )
243       {
244          mark = squareMark;
245          location = squareLocation;
246
247          addMouseListener(
248
249             new MouseAdapter() {
250
251                public void mouseReleased( MouseEvent e )
252                {
253                   setCurrentSquare( Square.this );
254                   sendClickedSquare( getSquareLocation() );
255                }
256
257             }  // end anonymous inner class
258
259          ); // end call to addMouseListener
260
261       }  // end Square constructor
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 5 of 6).

```
262
263        // return preferred size of Square
264        public Dimension getPreferredSize()
265        {
266           return new Dimension( 30, 30 );
267        }
268
269        // return minimum size of Square
270        public Dimension getMinimumSize()
271        {
272           return getPreferredSize();
273        }
274
275        // set mark for Square
276        public void setMark( char newMark )
277        {
278           mark = newMark;
279           repaint();
280        }
281
282        // return Square location
283        public int getSquareLocation()
284        {
285           return location;
286        }
287
288        // draw Square
289        public void paintComponent( Graphics g )
290        {
291           super.paintComponent( g );
292
293           g.drawRect( 0, 0, 29, 29 );
294           g.drawString( String.valueOf( mark ), 11, 20 );
295        }
296
297     }  // end class Square
298
299  }  // end class TicTacToeClient
```

Fig. 17.9 Client side of client/server Tic-Tac-Toe program (part 6 of 6).

If the message received is **`Valid move.`**, lines 143–159 display the message **`Valid move, please wait.`** and call class **`Square`**'s **`setMark`** method to set the client's mark in the current square (the one in which the user clicked) using **`SwingUtilities`** method **`invokeLater`** to ensure that the GUI updates occur in the event dispatch thread. If the message received is **`Invalid move, try again.`**, lines 162–165 display the message so the user can click a different square. If the message received is **`Opponent moved.`**, lines 168–195 read an integer from the server indicating where the opponent moved and place a mark in that square of the board (again using **`SwingUtilities`** method **`invokeLater`** to ensure that the GUI updates occur in the event dispatch thread). If any other message is received, line 206 simply displays the message.

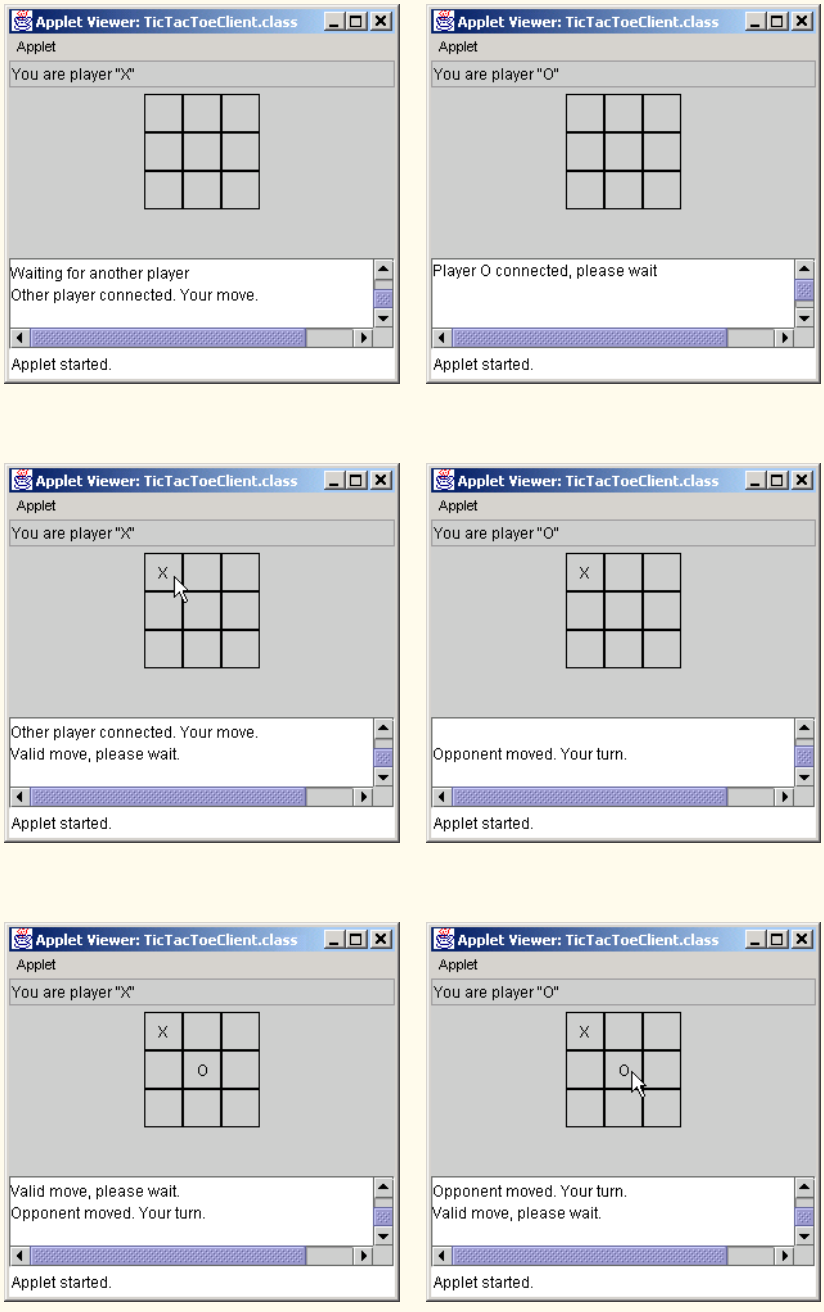


Fig. 17.10 Sample outputs from the client/server Tic-Tac-Toe program (part 1 of 2).

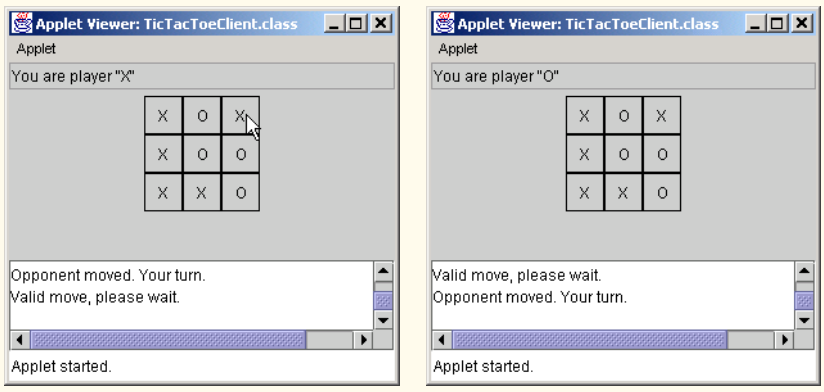


Fig. 17.10 Sample outputs from the client/server Tic-Tac-Toe program (part 2 of 2).

17.9 Security and the Network

As much as we look forward to writing a great variety of powerful network-based applications, our efforts may be crimped by limitations imposed on Java because of security concerns.c Many Web browsers, such as Netscape *Communicator* and Microsoft *Internet Explorer*, by default prohibit Java applets from doing file processing on the machines on which they execute. Think about it. A Java applet is designed to be sent to your browser via an HTML document that could be downloaded from any Web server in the world. Often you will know very little about the sources of Java applets that will execute on your system. To allow these applets free rein with your files could be disastrous.

A more subtle situation occurs with limiting the machines to which executing applets can connect. To build truly collaborative applications, we would ideally like to have our applets communicate with machines almost anywhere. The Java security manager in a Web browser often restricts an applet so that it can communicate only with the machine from which it was originally downloaded.

These restrictions might seem too harsh. However, the Java Security API now provides capabilities for signed applets that will enable browsers to determine whether an applet is downloaded from a *trusted source*. In cases where an applet is trusted, the applet can be given additional access to the computer on which the applet is executing. The features of the Java Security API and additional networking capabilities are discussed in our text *Advanced Java 2 Platform How to Program*.

17.10 DeitelMessenger Chat Server and Client

Chat rooms have become quite common on the Internet. Chat rooms provide a central location where users can chat with each other through short text messages. Each participant in a chat room can see all messages that other users post, and each user can post messages in the chat room. This section presents our capstone networking case study that integrates many of the Java networking, multithreading and Swing GUI features we have learned thus far to build an online chat system. We also introduce *multicast*, which enables an application to send **`DatagramPacket`**s to groups of clients. After reading this section, you will be able to build significant networking applications.

17.10.1 DeitelMessengerServer and Supporting Classes

The **DeitelMessengerServer** (Fig. 17.11) is the heart of the online chat system. Chat clients can participate in a chat by connecting to the **DeitelMessengerServer**. Method **startServer** (lines 19–54) launches **DeitelMessengerServer**. Lines 25–26 create a **ServerSocket** to accept incoming network connections. Recall that the **ServerSocket** constructor takes as its first argument the port on which the server should listen for incoming connections. Interface **SocketMessengerConstants** (Fig. 17.12) defines the port value as the constant **SERVER_PORT** to ensure that the server and the clients uses the correct port number. Class **DeitelMessengerServer** implements interface **SocketMessengerConstants** to facilitate referencing the constants defined in that interface.

```
1  // DeitelMessengerServer.java
2  // DeitelMessengerServer is a multi-threaded, socket- and
3  // packet-based chat server.
4  package com.deitel.messenger.sockets.server;
5
6  // Java core packages
7  import java.util.*;
8  import java.net.*;
9  import java.io.*;
10
11 // Deitel packages
12 import com.deitel.messenger.*;
13 import com.deitel.messenger.sockets.*;
14
15 public class DeitelMessengerServer implements MessageListener,
16    SocketMessengerConstants {
17
18    // start chat server
19    public void startServer()
20    {
21       // create server and manage new clients
22       try {
23
24          // create ServerSocket for incoming connections
25          ServerSocket serverSocket =
26             new ServerSocket( SERVER_PORT, 100 );
27
28          System.out.println( "Server listening on port " +
29             SERVER_PORT + " ..." );
30
31          // listen for clients constantly
32          while ( true ) {
33
34             // accept new client connection
35             Socket clientSocket = serverSocket.accept();
36
37             // create new ReceivingThread for receiving
38             // messages from client
```

Fig. 17.11 **DeitelMessengerServer** application for managing a chat room (part 1 of 2).

```
39                new ReceivingThread( this, clientSocket ).start();
40
41                // print connection information
42                System.out.println( "Connection received from: " +
43                   clientSocket.getInetAddress() );
44
45             } // end while
46
47          } // end try
48
49          // handle exception creating server and connecting clients
50          catch ( IOException ioException ) {
51             ioException.printStackTrace();
52          }
53
54       } // end method startServer
55
56       // when new message is received, broadcast message to clients
57       public void messageReceived( String from, String message )
58       {
59          // create String containing entire message
60          String completeMessage = from + MESSAGE_SEPARATOR + message;
61
62          // create and start MulticastSendingThread to broadcast
63          // new messages to all clients
64          new MulticastSendingThread(
65             completeMessage.getBytes() ).start();
66       }
67
68       // start the server
69       public static void main ( String args[] )
70       {
71          new DeitelMessengerServer().startServer();
72       }
73    }
```

```
Server listening on port 5000 ...
Connection received from: SEANSANTRY/XXX.XXX.XXX.XXX
Connection received from: PJD/XXX.XXX.XXX.XXX
```

Fig. 17.11 **DeitelMessengerServer** application for managing a chat room (part 2 of 2).

Lines 32–45 listen continuously for new client connections. Line 35 invokes method **accept** of class **ServerSocket** to wait for and accept a new client connection. Line 39 creates and starts a new **ReceivingThread** for the client. Class **ReceivingThread** (Fig. 17.14) is a **Thread** subclass that listens for new incoming messages from a particular client. The first argument to the **ReceivingThread** constructor is a **MessageListener** (Fig. 17.13), to which messages from the client should be delivered. Class **DeitelMessengerServer** implements interface **MessageListener** (line 15) and therefore can pass the **this** reference to the **ReceivingThread** constructor.

Method **messageReceived** (lines 57–66) is required by interface **MessageListener**. When each **ReceivingThread** receives a new message from a client, the **ReceivingThread** passes the message to a **MessageListener** through method **messageReceived**. Line 60 concatenates the **from String** with the separator **>>>** and the message body. Lines 64–65 create and **start** a new **MulticastSendingThread** to deliver **completeMessage** to all listening clients. Class **MulticastSendingThread** (Fig. 17.15) uses *multicast* as an efficient mechanism for sending one message to multiple clients. We discuss the details of multicasting shortly. Method **main** (lines 69–72) creates a new **DeitelMessengerServer** instance and starts the server.

Interface **SocketMessengerConstants** (Fig. 17.12) declares constants for use in the various classes that make up the Deitel messenger system. Classes can access these **static** constants either by referencing the constants through interface **SocketMessengerConstants** (e.g., **SocketMessengerConstants.SERVER_PORT**) or by implementing the interface and referencing the constants directly.

Line 9 defines the **String** constant **MULTICAST_ADDRESS**, which contains the address to which a **MulticastSendingThread** (Fig. 17.15) should send messages. This address is one of the addresses reserved for multicast, which we will describe soon. Line 12 defines the integer constant **MULTICAST_LISTENING_PORT**—the port on which clients should listen for new messages. Line 15 defines the integer constant **MULTICAST_SENDING_PORT**—the port to which a **MulticastSendingThread** should post new messages at the **MULTICAST_ADDRESS**. Line 18 defines the integer constant **SERVER_PORT**—the port on which **DeitelMessengerServer** listens for incoming client connections. Line 21 defines **String** constant **DISCONNECT_STRING**, which is the **String** that a client sends to **DeitelMessengerServer** when the user wishes to leave the chat room. Line 24 defines **String** constant **MESSAGE_SEPARATOR**, which separates the user name from the message body. Line 27 specifies the maximum message size in bytes.

```
1  // SocketMessengerConstants.java
2  // SocketMessengerConstants defines constants for the port numbers
3  // and multicast address in DeitelMessenger
4  package com.deitel.messenger.sockets;
5
6  public interface SocketMessengerConstants {
7
8     // address for multicast datagrams
9     public static final String MULTICAST_ADDRESS = "230.0.0.1";
10
11    // port for listening for multicast datagrams
12    public static final int MULTICAST_LISTENING_PORT = 5555;
13
14    // port for sending multicast datagrams
15    public static final int MULTICAST_SENDING_PORT = 5554;
16
17    // port for Socket connections to DeitelMessengerServer
18    public static final int SERVER_PORT = 5000;
```

Fig. 17.12 **SocketMessengerConstants** declares constants for use throughout the **DeitelMessengerServer** and **DeitelMessenger** applications (part 1 of 2).

```
19
20    // String that indicates disconnect
21    public static final String DISCONNECT_STRING = "DISCONNECT";
22
23    // String that separates the user name from the message body
24    public static final String MESSAGE_SEPARATOR = ">>>";
25
26    // message size (in bytes)
27    public static final int MESSAGE_SIZE = 512;
28 }
```

Fig. 17.12 **SocketMessengerConstants** declares constants for use throughout the **DeitelMessengerServer** and **DeitelMessenger** applications (part 2 of 2).

Many different classes in the Deitel messenger system receive messages. For example, **DeitelMessengerServer** receives messages from clients and delivers those messages to all chat room participants. As we will see, the user interface for each client also receives messages and displays those messages to the users. Each of the classes that receives messages implements interface **MessageListener** (Fig. 17.13). The interface declares method **messageReceived**, which allows an implementing class to receive chat messages. Method **messageReceived** takes two **String** arguments representing the name of the user who sent the message and the message body, respectively.

DeitelMessengerServer uses instances of class **ReceivingThread** (Fig. 17.14) to listen for new messages from each client. Class **ReceivingThread** extends class **Thread**. This enables **DeitelMessengerServer** to create an object of class **ReceivingThread** for each client, to handle messages from multiple clients at once. When **DeitelMessengerServer** receives a new client connection, **DeitelMessengerServer** creates a new **ReceivingThread** for the client, then continues listening for new client connections. The **ReceivingThread** listens for new messages from a single client and passes those messages back to the **DeitelMessengerServer** through method **messageReceived**.

```
1  // MessageListener.java
2  // MessageListener is an interface for classes that wish to
3  // receive new chat messages.
4  package com.deitel.messenger;
5
6  public interface MessageListener {
7
8     // receive new chat message
9     public void messageReceived( String from, String message );
10 }
```

Fig. 17.13 **MessageListener** interface that defines method **messageReceived** for receiving new chat messages.

```
1  // ReceivingThread.java
2  // ReceivingThread is a Thread that listens for messages
3  // from a particular client and delivers messages to a
4  // MessageListener.
5  package com.deitel.messenger.sockets.server;
6
7  // Java core packages
8  import java.io.*;
9  import java.net.*;
10 import java.util.StringTokenizer;
11
12 // Deitel packages
13 import com.deitel.messenger.*;
14 import com.deitel.messenger.sockets.*;
15
16 public class ReceivingThread extends Thread implements
17    SocketMessengerConstants {
18
19    private BufferedReader input;
20    private MessageListener messageListener;
21    private boolean keepListening = true;
22
23    // ReceivingThread constructor
24    public ReceivingThread( MessageListener listener,
25       Socket clientSocket )
26    {
27       // invoke superclass constructor to name Thread
28       super( "ReceivingThread: " + clientSocket );
29
30       // set listener to which new messages should be sent
31       messageListener = listener;
32
33       // set timeout for reading from clientSocket and create
34       // BufferedReader for reading incoming messages
35       try {
36          clientSocket.setSoTimeout( 5000 );
37
38          input = new BufferedReader( new InputStreamReader(
39             clientSocket.getInputStream() ) );
40       }
41
42       // handle exception creating BufferedReader
43       catch ( IOException ioException ) {
44          ioException.printStackTrace();
45       }
46
47    } // end ReceivingThread constructor
48
49    // listen for new messages and deliver them to MessageListener
50    public void run()
51    {
52       String message;
```

Fig. 17.14 **ReceivingThread** for listening for new messages from **DeitelMessengerServer** clients in separate **Thread**s (part 1 of 3).

```
53
54          // listen for messages until stopped
55          while ( keepListening ) {
56
57             // read message from BufferedReader
58             try {
59                message = input.readLine();
60             }
61
62             // handle exception if read times out
63             catch ( InterruptedIOException interruptedIOException ) {
64
65                // continue to next iteration to keep listening
66                continue;
67             }
68
69             // handle exception reading message
70             catch ( IOException ioException ) {
71                ioException.printStackTrace();
72                break;
73             }
74
75             // ensure non-null message
76             if ( message != null ) {
77
78                // tokenize message to retrieve user name
79                // and message body
80                StringTokenizer tokenizer =
81                   new StringTokenizer( message, MESSAGE_SEPARATOR );
82
83                // ignore messages that do not contain a user
84                // name and message body
85                if ( tokenizer.countTokens() == 2 ) {
86
87                   // send message to MessageListener
88                   messageListener.messageReceived(
89                      tokenizer.nextToken(),    // user name
90                      tokenizer.nextToken() ); // message body
91                }
92
93                else
94
95                   // if disconnect message received, stop listening
96                   if ( message.equalsIgnoreCase( MESSAGE_SEPARATOR +
97                      DISCONNECT_STRING ) ) {
98
99                      stopListening();
100                  }
101
102            }  // end if
103
104         } // end while
```

Fig. 17.14 **ReceivingThread** for listening for new messages from **DeitelMessengerServer** clients in separate **Thread**s (part 2 of 3).

```
105
106        // close BufferedReader (also closes Socket)
107        try {
108           input.close();
109        }
110
111        // handle exception closing BufferedReader
112        catch ( IOException ioException ) {
113           ioException.printStackTrace();
114        }
115
116     } // end method run
117
118     // stop listening for incoming messages
119     public void stopListening()
120     {
121        keepListening = false;
122     }
123  }
```

Fig. 17.14 **ReceivingThread** for listening for new messages from **DeitelMessengerServer** clients in separate **Thread**s (part 3 of 3).

The **ReceivingThread** constructor (lines 24–47) takes as its first argument a **MessageListener**. The **ReceivingThread** will deliver new messages to this **MessageListener** by invoking method **messageReceived** of interface **MessageListener**. The **Socket** argument to the **ReceivingThread** constructor is the connection to a particular client. Line 28 invokes the **Thread** constructor to provide a unique name for each **ReceivingThread** instance. Naming the **ReceivingThread** this way can be useful when debugging the application. Line 31 sets the **MessageListener** to which the **ReceivingThread** should deliver new messages. Line 36 invokes method **setSoTimeout** of class **Socket** with an integer argument of **5000** milliseconds. Reading data from a **Socket** is a *blocking call*—the current thread is put in the blocked state (Fig. 15.1) while the thread waits for the read operation to complete. Method **setSoTimeout** specifies that, if no data is received in the given number of milliseconds, the **Socket** should issue an **InterruptedIOException**, which the current thread can catch, then continue executing. This technique prevents the current thread from deadlocking if no more data is available from the **Socket**. Lines 38–39 create a new **BufferedReader** for the **clientSocket**'s **InputStream**. The **ReceivingThread** uses this **BufferedReader** to read new messages from the client.

Method **run** (lines 50–116) listens continuously for new messages from the client. Lines 55–104 loop as long as the **boolean** variable **keepListening** is **true**. Line 59 invokes **BufferedReader** method **readLine** to read a line of data from the client. If more than **5000** milliseconds pass without reading any data, method **readLine** throws an **InterruptedIOException**, which indicates that the timeout set on line 36 has expired. Line 66 uses keyword **continue** to go to the next iteration of the **while** loop to continue listening for messages. Lines 70–73 catch an **IOException**, which indicates a more severe problem from method **readLine**. Line 71 prints a stack trace to aid in debugging the application, and line 72 uses keyword **break** to terminate the **while** loop.

When a client sends a message to the server, the client separates the user's name from the message body with the String **MESSAGE_SEPARATOR**. If there are no exceptions thrown when reading data from the client and the message is not **null** (line 76), lines 80–81 create a new **StringTokenizer**. This **StringTokenizer** separates each message into two tokens delimited by **MESSAGE_SEPARATOR**. The first token is the sender's user name; the second token is the message. Line 85 checks for the proper number of tokens, and lines 88–90 invoke method **messageReceived** of interface **MessageListener** to deliver the new message to the registered **MessageListener**. If the **StringTokenizer** does not produce two tokens, lines 96–97 check the message to see whether it matches the constant **DISCONNECT_STRING**, which would indicate that the user wishes to leave the chat room. If the **String**s match, line 99 invokes **ReceivingThread** method **stopListening** to terminate the **ReceivingThread**.

Method **stopListening** (lines 119–122) sets boolean variable **keepListening** to **false**. This causes the **while** loop condition on line 55 to fail and causes the **ReceivingThread** to close the client **Socket** (line 108). Then, method **run** returns, which terminates the **ReceivingThread**'s execution.

MulticastSendingThread (Fig. 17.15) delivers **DatagramPacket**s containing chat messages to a group of clients. Multicast is an efficient way to send data to many clients without the overhead of broadcasting that data to every host on the Internet. To understand multicast, let us look at a real-world analogy—the relationship between a magazine publisher and that magazine's subscribers. The magazine publisher produces a magazine and provides the magazine to a distributor. Customers interested in that magazine obtain a subscription and begin receiving the magazine in the mail from the distributor. This communication is quite different from a television broadcast. When a television station produces a television program, the station broadcasts that television show throughout a geographical region or perhaps throughout the world by using satellites. Broadcasting a television show for 10,000 viewers is no more expensive to the television station than broadcasting a television show for 100 viewers—the radio signal carrying the broadcast reaches a wide area. However, printing and delivering a magazine to 10,000 readers would be much more expensive than printing and delivering the magazine to 100 readers. Most magazine publishers could not stay in business if they had to broadcast their magazines to everyone, so magazine publishers multicast their magazines to a group of subscribers instead.

Using multicast, an application can "publish" **DatagramPacket**s to be delivered to other applications—the "subscribers." An application multicasts **DatagramPacket**s by sending the **DatagramPacket**s to a *multicast address*, which is an IP address reserved for multicast in the range from **224.0.0.0** to **239.255.255.255**. Clients that wish to receive these **DatagramPacket**s can connect to the appropriate multicast address to join the group of subscribers—the *multicast group*. When an application sends a **DatagramPacket** to the multicast address, each client in the multicast group receives the **DatagramPacket**. Multicast **DatagramPacket**s, like unicast **DatagramPacket**s (Fig. 17.7), are not reliable—packets are not guaranteed to reach any destination. Also, the order in which the particular clients receive the datagrams is not guaranteed.

Class **MulticastSendingThread** extends class **Thread** to enable **DeitelMessengerServer** to send multicast messages in a separate thread. Each time **DeitelMessengerServer** needs to multicast a message, the server creates a new **MulticastSendingThread** with the contents of the message and starts the thread.

The **MulticastSendingThread** constructor (lines 20–26) takes as an argument an array of **byte**s containing the message.

```
1  // MulticastSendingThread.java
2  // MulticastSendingThread is a Thread that broadcasts a chat
3  // message using a multicast datagram.
4  package com.deitel.messenger.sockets.server;
5
6  // Java core packages
7  import java.io.*;
8  import java.net.*;
9
10 // Deitel packages
11 import com.deitel.messenger.sockets.*;
12
13 public class MulticastSendingThread extends Thread
14    implements SocketMessengerConstants {
15
16    // message data
17    private byte[] messageBytes;
18
19    // MulticastSendingThread constructor
20    public MulticastSendingThread( byte[] bytes )
21    {
22       // invoke superclass constructor to name Thread
23       super( "MulticastSendingThread" );
24
25       messageBytes = bytes;
26    }
27
28    // deliver message to MULTICAST_ADDRESS over DatagramSocket
29    public void run()
30    {
31       // deliver message
32       try {
33
34          // create DatagramSocket for sending message
35          DatagramSocket socket =
36             new DatagramSocket( MULTICAST_SENDING_PORT );
37
38          // use InetAddress reserved for multicast group
39          InetAddress group = InetAddress.getByName(
40             MULTICAST_ADDRESS );
41
42          // create DatagramPacket containing message
43          DatagramPacket packet = new DatagramPacket(
44             messageBytes, messageBytes.length, group,
45             MULTICAST_LISTENING_PORT );
46
47          // send packet to multicast group and close socket
48          socket.send( packet );
```

Fig. 17.15 **MulticastSendingThread** for delivering outgoing messages to a multicast group via **DatagramPacket**s.

```
49             socket.close();
50          }
51
52          // handle exception delivering message
53          catch ( IOException ioException ) {
54             ioException.printStackTrace();
55          }
56
57       } // end method run
58    }
```

Fig. 17.15 **MulticastSendingThread** for delivering outgoing messages to a multicast group via **DatagramPacket**s.

Method **run** (lines 29–57) delivers the message to the multicast address. Lines 35–36 create a new **DatagramSocket**. Recall from the packet-networking example that we used **DatagramSocket**s to send *unicast* **DatagramPacket**s—packets sent from one host directly to another host. Delivering **DatagramPacket**s by using multicast is exactly the same, except the address to which the **DatagramPacket**s are sent is a multicast address in the range from **224.0.0.0** to **239.255.255.255**. Lines 39–40 create an **InetAddress** object for the multicast address, which is defined as a constant in interface **SocketMessengerConstants**. Lines 43–45 create the **DatagramPacket** containing the message. The first argument to the **DatagramPacket** constructor is the **byte** array containing the message. The second argument is the length of the **byte** array. The third argument specifies the **InetAddress** to which the packet should be sent, and the last argument specifies the port number through which the packet should be delivered to the multicast address. Line 48 invokes method **send** of class **DatagramSocket** to send the **DatagramPacket**. When the **DatagramPacket** is delivered to the multicast address, all clients listening to that multicast address on the proper port receive the **DatagramPacket**. Line 49 closes the **DatagramSocket**, and the run method returns, terminating the **MulticastSendingThread**.

17.10.2 DeitelMessenger Client and Supporting Classes

The client for the **DeitelMessengerServer** consists of several pieces. A class that implements interface **MessageManager** (Fig. 17.16) manages communication with the server. A **Thread** subclass listens for messages at **DeitelMessengerServer**'s multicast address. Another **Thread** subclass sends messages from the client to **DeitelMessengerServer**. A **JFrame** subclass provides a GUI for the client.

Interface **MessageManager** (Fig. 17.16) defines methods for managing communication with **DeitelMessengerServer**. We define this interface to abstract the base functionality a client needs to interact with a chat server from the underlying communication mechanism needed to communicate with that chat server. This abstraction enables us to provide **MessageManager** implementations that use other network protocols to implement the communication details. For example, if we want to connect to a different chat server that does not use multicast **DatagramPacket**s, we could implement the **MessageManager** interface with the appropriate network protocols for this alternate messaging server. We would not need to modify any other code in the client, because the

other components of the client refer only to interface **MessageManager**, and not to some particular **MessageManager** implementation. Likewise, the **MessageManager** interface methods refer to other components of the client only through interface **MessageListener**. Therefore, other components of the client can change without requiring changes in the **MessageManager** or its implementations.Method **connect** (line 10) connects **MessageManager** to **DeitelMessengerServer** and routes incoming messages to the appropriate **MessageListener**. Method **disconnect** (line 14) disconnects the **MessageManager** from the **DeitelMessengerServer** and stops delivering messages to the given **MessageListener**. Method **sendMessage** (line 17) sends a new message to **DeitelMessengerServer**.

Class **SocketMessageManager** (Fig. 17.17) implements interface **MessageManager** (line 16), using **Socket**s and **MulticastSocket**s to communicate with **DeitelMessengerServer** and receive incoming messages. Line 20 declares the **Socket** that **SocketMessageManager** uses to connect and send messages to **DeitelMessengerServer**. Line 26 declares the **PacketReceivingThread** (Fig. 17.19) that listens for new incoming messages. The **boolean** flag **connected** (line 29) indicates whether the **SocketMessageManager** is connected to **DeitelMessengerServer**. \

```
1  // MessageManager.java
2  // MessageManager is an interface for objects capable of managing
3  // communications with a message server.
4  package com.deitel.messenger;
5
6  public interface MessageManager {
7
8     // connect to message server and route incoming messages
9     // to given MessageListener
10    public void connect( MessageListener listener );
11
12    // disconnect from message server and stop routing
13    // incoming messages to given MessageListener
14    public void disconnect( MessageListener listener );
15
16    // send message to message server
17    public void sendMessage( String from, String message );
18 }
```

Fig. 17.16 **MessageManager** interface that defines methods for communicating with a **DeitelMessengerServer**.

```
1  // SocketMessageManager.java
2  // SocketMessageManager is a MessageManager implementation for
3  // communicating with a DeitelMessengerServer using Sockets
4  // and MulticastSockets.
5  package com.deitel.messenger.sockets.client;
6
```

Fig. 17.17 **SocketMessageManager** implementation of interface **MessageManager** for communicating via **Socket**s and multicast **DatagramPacket**s (part 1 of 4).

```
 7  // Java core packages
 8  import java.util.*;
 9  import java.net.*;
10  import java.io.*;
11
12  // Deitel packages
13  import com.deitel.messenger.*;
14  import com.deitel.messenger.sockets.*;
15
16  public class SocketMessageManager implements MessageManager,
17     SocketMessengerConstants {
18
19     // Socket for outgoing messages
20     private Socket clientSocket;
21
22     // DeitelMessengerServer address
23     private String serverAddress;
24
25     // Thread for receiving multicast messages
26     private PacketReceivingThread receivingThread;
27
28     // flag indicating connection status
29     private boolean connected = false;
30
31     // SocketMessageManager constructor
32     public SocketMessageManager( String address )
33     {
34        serverAddress = address;
35     }
36
37     // connect to server and send messages to given MessageListener
38     public void connect( MessageListener listener )
39     {
40        // if already connected, return immediately
41        if ( connected )
42           return;
43
44        // open Socket connection to DeitelMessengerServer
45        try {
46           clientSocket = new Socket(
47              InetAddress.getByName( serverAddress ), SERVER_PORT );
48
49           // create Thread for receiving incoming messages
50           receivingThread = new PacketReceivingThread( listener );
51           receivingThread.start();
52
53           // update connected flag
54           connected = true;
55
56        } // end try
57
```

Fig. 17.17 **SocketMessageManager** implementation of interface **MessageManager** for communicating via **Socket**s and multicast **DatagramPacket**s (part 2 of 4).

```
58          // handle exception connecting to server
59          catch ( IOException ioException ) {
60             ioException.printStackTrace();
61          }
62
63       } // end method connect
64
65       // disconnect from server and unregister given MessageListener
66       public void disconnect( MessageListener listener )
67       {
68          // if not connected, return immediately
69          if ( !connected )
70             return;
71
72          // stop listening thread and disconnect from server
73          try {
74
75             // notify server that client is disconnecting
76             Thread disconnectThread = new SendingThread(
77                clientSocket, "", DISCONNECT_STRING );
78             disconnectThread.start();
79
80             // wait 10 seconds for disconnect message to be sent
81             disconnectThread.join( 10000 );
82
83             // stop receivingThread and remove given MessageListener
84             receivingThread.stopListening();
85
86             // close outgoing Socket
87             clientSocket.close();
88
89          } // end try
90
91          // handle exception disconnecting from server
92          catch ( IOException ioException ) {
93             ioException.printStackTrace();
94          }
95
96          // handle exception joining disconnectThread
97          catch ( InterruptedException interruptedException ) {
98             interruptedException.printStackTrace();
99          }
100
101         // update connected flag
102         connected = false;
103
104      } // end method disconnect
105
106      // send message to server
107      public void sendMessage( String from, String message )
108      {
```

Fig. 17.17 **SocketMessageManager** implementation of interface **MessageManager** for communicating via **Socket**s and multicast **DatagramPacket**s (part 3 of 4).

```
109         // if not connected, return immediately
110         if ( !connected )
111            return;
112
113         // create and start new SendingThread to deliver message
114         new SendingThread( clientSocket, from, message).start();
115      }
116   }
```

Fig. 17.17 **SocketMessageManager** implementation of interface **MessageManager** for communicating via **Socket**s and multicast **DatagramPacket**s (part 4 of 4).

The **SocketMessageManager** constructor (lines 32–35) receives the address of the **DeitelMessengerServer** to which **SocketMessageManager** should connect. Method **connect** (lines 38–63) connects **SocketMessageManager** to **DeitelMessengerServer**. If **SocketMessageManager** was connected previously, line 42 returns from method **connect**. Lines 46–47 create a new **Socket** to communicate with **DeitelMessengerServer**. Line 47 creates an **InetAddress** object for the server's address and uses the constant **SERVER_PORT** to specify the port on which the client should connect. Line 50 creates a new **PacketReceivingThread**, which listens for incoming multicast messages from **DeitelMessengerServer**. Line 51 starts **PacketReceivingThread**. Line 54 updates **boolean** variable **connected** to indicate that **SocketMessageManager** is connected to the server.

Method **disconnect** (lines 66–104) terminates the **SocketMessageManager**'s connection to **DeitelMessengerServer**. If **SocketMessageManager** is not connected, line 70 returns from method **disconnect**. Lines 76–77 create a new **SendingThread** (Fig. 17.18) to send **DISCONNECT_STRING** to **DeitelMessengerServer**. Class **SendingThread** delivers a message to **DeitelMessengerServer** over the **SocketMessageManager**'s **Socket** connection. Line 78 starts the **SendingThread** to deliver the message. Line 81 invokes **SendingThread** method **join** (inherited from **Thread**) to wait for the disconnect message to be delivered. The integer argument **10000** specifies that the current thread should wait only 10 seconds to **join** the **SendingThread** before continuing. Once the disconnect message has been delivered, line 84 invokes method **stopListening** of class **PacketReceivingThread** to stop receiving incoming chat messages. Line 87 closes the **Socket** connection to **DeitelMessengerServer**.

Method **sendMessage** (lines 107–115) sends an outgoing message to **DeitelMessengerServer**. If **SocketMessageManager** is not connected, line 111 returns from method **sendMessage**. Line 114 creates and starts a new **SendingThread** instance (Fig. 17.18) to deliver the new message in a separate thread of execution.

Class **SendingThread** (Fig. 17.18) extends class **Thread** to deliver outgoing messages to the **DeitelMessengerServer** in a separate thread of execution. **SendingThread**'s constructor (lines 21–31) takes as arguments the **Socket** over which to send the message, the **userName** from whom the message came and the **message** body. Line 30 concatenates **userName**, **MESSAGE_SEPARATOR** and **message** to build **messageToSend**. Constant **MESSAGE_SEPARATOR** enables the message recipient to parse the message into two parts—the sending user's name and the message body—by using a **StringTokenizer**.

```
1  // SendingThread.java
2  // SendingThread sends a message to the chat server in a
3  // separate Thread.
4  package com.deitel.messenger.sockets.client;
5
6  // Java core packages
7  import java.io.*;
8  import java.net.*;
9
10 // Deitel packages
11 import com.deitel.messenger.sockets.*;
12
13 public class SendingThread extends Thread
14    implements SocketMessengerConstants {
15
16    // Socket over which to send message
17    private Socket clientSocket;
18    private String messageToSend;
19
20    // SendingThread constructor
21    public SendingThread( Socket socket, String userName,
22       String message )
23    {
24       // invoke superclass constructor to name Thread
25       super( "SendingThread: " + socket );
26
27       clientSocket = socket;
28
29       // build the message to be sent
30       messageToSend = userName + MESSAGE_SEPARATOR + message;
31    }
32
33    // send message and exit Thread
34    public void run()
35    {
36       // send message and flush PrintWriter
37       try {
38          PrintWriter writer =
39             new PrintWriter( clientSocket.getOutputStream() );
40          writer.println( messageToSend );
41          writer.flush();
42       }
43
44       // handle exception sending message
45       catch ( IOException ioException ) {
46          ioException.printStackTrace();
47       }
48
49    } // end method run
50 }
```

Fig. 17.18 **SendingThread** for delivering outgoing messages to **DeitelMessengerServer**.

Method **run** (lines 34–49) delivers the complete message to **DeitelMessengerServer**, using the **Socket** provided to the **SendingThread** constructor. Lines 38–39 create a new **PrintWriter** for the **clientSocket**'s **OutputStream**. Line 40 invokes method **println** of class **PrintWriter** to send the message. Line 41 invokes method **flush** of class **PrintWriter** to ensure that the message is sent immediately. Note that class **SendingThread** does not close the **clientSocket**. Class **SocketMessageManager** uses a new instance of class **SendingThread** for each message the client sends, so the **clientSocket** must remain open until the user disconnects from **DeitelMessengerServer**.

Class **PacketReceivingThread** extends class **Thread** to enable **SocketMessageManager** to listen for incoming messages in a separate thread of execution. Line 19 declares the **MessageListener** to which **PacketReceivingThread** will deliver incoming messages. Line 22 declares a **MulticastSocket**, which enables **PacketReceivingThread** to receive multicast **DatagramPacket**s. Line 25 declares an **InetAddress** reference for the multicast address to which **DeitelMessengerServer** posts new chat messages. The **MulticastSocket** connects to this **InetAddress** to listen for incoming chat messages.

```
1  // PacketReceivingThread.java
2  // PacketReceivingThread listens for DatagramPackets containing
3  // messages from a DeitelMessengerServer.
4  package com.deitel.messenger.sockets.client;
5
6  // Java core packages
7  import java.io.*;
8  import java.net.*;
9  import java.util.*;
10
11 // Deitel packages
12 import com.deitel.messenger.*;
13 import com.deitel.messenger.sockets.*;
14
15 public class PacketReceivingThread extends Thread
16    implements SocketMessengerConstants {
17
18    // MessageListener to whom messages should be delivered
19    private MessageListener messageListener;
20
21    // MulticastSocket for receiving broadcast messages
22    private MulticastSocket multicastSocket;
23
24    // InetAddress of group for messages
25    private InetAddress multicastGroup;
26
27    // flag for terminating PacketReceivingThread
28    private boolean keepListening = true;
29
```

Fig. 17.19 **PacketReceivingThread** for listening for new multicast messages from **DeitelMessengerServer** in a separate **Thread** (part 1 of 4).

```
30     // PacketReceivingThread constructor
31     public PacketReceivingThread( MessageListener listener )
32     {
33        // invoke superclass constructor to name Thread
34        super( "PacketReceivingThread" );
35
36        // set MessageListener
37        messageListener = listener;
38
39        // connect MulticastSocket to multicast address and port
40        try {
41           multicastSocket =
42              new MulticastSocket( MULTICAST_LISTENING_PORT );
43
44           multicastGroup =
45              InetAddress.getByName( MULTICAST_ADDRESS );
46
47           // join multicast group to receive messages
48           multicastSocket.joinGroup( multicastGroup );
49
50           // set 5 second time-out when waiting for new packets
51           multicastSocket.setSoTimeout( 5000 );
52        }
53
54        // handle exception connecting to multicast address
55        catch ( IOException ioException ) {
56           ioException.printStackTrace();
57        }
58
59     } // end PacketReceivingThread constructor
60
61     // listen for messages from multicast group
62     public void run()
63     {
64        // listen for messages until stopped
65        while ( keepListening ) {
66
67           // create buffer for incoming message
68           byte[] buffer = new byte[ MESSAGE_SIZE ];
69
70           // create DatagramPacket for incoming message
71           DatagramPacket packet = new DatagramPacket( buffer,
72              MESSAGE_SIZE );
73
74           // receive new DatagramPacket (blocking call)
75           try {
76              multicastSocket.receive( packet );
77           }
78
79           // handle exception when receive times out
80           catch ( InterruptedIOException interruptedIOException ) {
81
```

Fig. 17.19 **PacketReceivingThread** for listening for new multicast messages from **DeitelMessengerServer** in a separate **Thread** (part 2 of 4).

```
82             // continue to next iteration to keep listening
83             continue;
84          }
85
86          // handle exception reading packet from multicast group
87          catch ( IOException ioException ) {
88             ioException.printStackTrace();
89             break;
90          }
91
92          // put message data in a String
93          String message = new String( packet.getData() );
94
95          // ensure non-null message
96          if ( message != null ) {
97
98             // trim extra whitespace from end of message
99             message = message.trim();
100
101            // tokenize message to retrieve user name
102            // and message body
103            StringTokenizer tokenizer =
104               new StringTokenizer( message, MESSAGE_SEPARATOR );
105
106            // ignore messages that do not contain a user
107            // name and message body
108            if ( tokenizer.countTokens() == 2 ) {
109
110               // send message to MessageListener
111               messageListener.messageReceived(
112                  tokenizer.nextToken(),    // user name
113                  tokenizer.nextToken() ); // message body
114            }
115
116         } // end if
117
118      } // end while
119
120      // leave multicast group and close MulticastSocket
121      try {
122         multicastSocket.leaveGroup( multicastGroup );
123         multicastSocket.close();
124      }
125
126      // handle exception reading packet from multicast group
127      catch ( IOException ioException ) {
128         ioException.printStackTrace();
129      }
130
131   } // end method run
132
```

Fig. 17.19 **PacketReceivingThread** for listening for new multicast messages from **DeitelMessengerServer** in a separate **Thread** (part 3 of 4).

```
133     // stop listening for new messages
134     public void stopListening()
135     {
136        // terminate Thread
137        keepListening = false;
138     }
139  }
```

Fig. 17.19 **PacketReceivingThread** for listening for new multicast messages from **DeitelMessengerServer** in a separate **Thread** (part 4 of 4).

The **PacketReceivingThread** constructor (lines 31–59) takes as an argument the **MessageListener** to which the **PacketReceivingThread** should deliver incoming messages. Recall that interface **MessageListener** defines a single method **messageReceived**. When the **PacketReceivingThread** receives a new chat message over the **MulticastSocket**, **PacketReceivingThread** invokes method **messageReceived** to deliver the new message to the **MessageListener**.

Lines 41–42 create a new **MulticastSocket** and pass to the **MulticastSocket** constructor the constant **MULTICAST_LISTENING_PORT** from interface **SocketMessengerConstants**. This argument specifies the port on which the **MulticastSocket** should listen for incoming chat messages. Lines 44–45 create an **InetAddress** object for the **MULTICAST_ADDRESS**, to which **DeitelMessengerServer** multicasts new chat messages. Line 48 invokes method **joinGroup** of class **MulticastSocket** to register the **MulticastSocket** to receive messages sent to **MULTICAST_ADDRESS**. Line 51 invokes **MulticastSocket** method **setSoTime-out** to specify that, if no data is received in **5000** milliseconds, the **MulticastSocket** should issue an **InterruptedIOException**, which the current thread can catch, then continue executing. This approach prevents **PacketReceivingThread** from deadlocking when waiting for incoming data. Also, if the **MulticastSocket** did not ever time out, the **while** loop would not be able to check the **keepListening** variable and would therefore prevent **PacketReceivingThread** from stopping if **keepListening** were set to **false**.

Method **run** (lines 62–131) listens for incoming multicast messages. Line 68 creates a **byte** array in which to store the incoming **DatagramPacket** data. Lines 71–72 create a **DatagramPacket** to store the incoming message. Line 76 invokes method **receive** of class **MulticastSocket** with the **DatagramPacket** packet as an argument. This is a blocking call that reads an incoming packet from the multicast address. If **5000** milliseconds pass without receipt of a packet, method **receive** throws an **InterruptedIOException**, because we previously set a **5000** millisecond time-out (line 51). Line 83 uses keyword **continue** to proceed to the next **while** loop iteration to continue listening for incoming messages. For other **IOException**s, line 89 **break**s the **while** loop to terminate the **PacketReceivingThread**.

Line 93 invokes method **getData** of class **DatagramPacket** to retrieve the message data. Line 99 invokes method **trim** of class **String** to remove extra whitespace from the end of the message. Recall that **DatagramPacket**s are a fixed size—**512** bytes in this example—so, if the message is shorter than **512** bytes, there will be extra whitespace after the message. Lines 103–104 create a **StringTokenizer** to separate the message body from the name of the user who sent the message. Line 108 checks for the correct number of tokens. Lines 111–113 invoke method **messageReceived** of inter-

face **MessageListener** to deliver the incoming message to the **PacketReceivingThread**'s **MessageListener**.

If the program invokes method **stopListening** (lines 134–138), the **while** loop in method **run** (lines 62–118) terminates. Line 122 invokes method **leaveGroup** of class **MulticastSocket** to stop receiving messages from the multicast address. Line 123 invokes method **close** of class **MulticastSocket** to close the **MulticastSocket**. **PacketReceivingThread** then terminates when method **run** returns.

Class **ClientGUI** (Fig. 17.20) extends class **JFrame** to create a GUI for a user to send and receive chat messages. The GUI consists of a **JTextArea** for displaying incoming messages (line 22), a **JTextArea** for entering new messages (line 23), **JButton**s and **JMenuItem**s for connecting to and disconnecting from the server (lines 26–29) and a **JButton** for sending messages (line 32). The GUI also contains a **JLabel** that displays whether the client is connected or disconnected.

```
1  // ClientGUI.java
2  // ClientGUI provides a user interface for sending and receiving
3  // messages to and from the DeitelMessengerServer.
4  package com.deitel.messenger;
5
6  // Java core packages
7  import java.io.*;
8  import java.net.*;
9  import java.awt.*;
10 import java.awt.event.*;
11
12 // Java standard extensions
13 import javax.swing.*;
14 import javax.swing.border.*;
15
16 public class ClientGUI extends JFrame {
17
18    // JMenu for connecting/disconnecting server
19    private JMenu serverMenu;
20
21    // JTextAreas for displaying and inputting messages
22    private JTextArea messageArea;
23    private JTextArea inputArea;
24
25    // JButtons and JMenuItems for connecting and disconnecting
26    private JButton connectButton;
27    private JMenuItem connectMenuItem;
28    private JButton disconnectButton;
29    private JMenuItem disconnectMenuItem;
30
31    // JButton for sending messages
32    private JButton sendButton;
33
34    // JLabel for displaying connection status
35    private JLabel statusBar;
```

Fig. 17.20 **ClientGUI** subclass of **JFrame** for presenting a GUI for viewing and sending chat messages (part 1 of 6).

```
36
37     // userName to add to outgoing messages
38     private String userName;
39
40     // MessageManager for communicating with server
41     private MessageManager messageManager;
42
43     // MessageListener for receiving incoming messages
44     private MessageListener messageListener;
45
46     // ClientGUI constructor
47     public ClientGUI( MessageManager manager )
48     {
49        super( "Deitel Messenger" );
50
51        // set the MessageManager
52        messageManager = manager;
53
54        // create MyMessageListener for receiving messages
55        messageListener = new MyMessageListener();
56
57        // create File JMenu
58        serverMenu = new JMenu ( "Server" );
59        serverMenu.setMnemonic( 'S' );
60        JMenuBar menuBar = new JMenuBar();
61        menuBar.add( serverMenu );
62        setJMenuBar( menuBar );
63
64        // create ImageIcon for connect buttons
65        Icon connectIcon = new ImageIcon(
66           getClass().getResource( "images/Connect.gif" ) );
67
68        // create connectButton and connectMenuItem
69        connectButton = new JButton( "Connect", connectIcon );
70        connectMenuItem = new JMenuItem( "Connect", connectIcon );
71        connectMenuItem.setMnemonic( 'C' );
72
73        // create ConnectListener for connect buttons
74        ActionListener connectListener = new ConnectListener();
75        connectButton.addActionListener( connectListener );
76        connectMenuItem.addActionListener( connectListener );
77
78        // create ImageIcon for disconnect buttons
79        Icon disconnectIcon = new ImageIcon(
80           getClass().getResource( "images/Disconnect.gif" ) );
81
82        // create disconnectButton and disconnectMenuItem
83        disconnectButton = new JButton( "Disconnect",
84           disconnectIcon );
85        disconnectMenuItem = new JMenuItem( "Disconnect",
86           disconnectIcon );
87        disconnectMenuItem.setMnemonic( 'D' );
```

Fig. 17.20 **`ClientGUI`** subclass of **`JFrame`** for presenting a GUI for viewing and sending chat messages (part 2 of 6).

```
88
89          // disable disconnect buttons
90          disconnectButton.setEnabled( false );
91          disconnectMenuItem.setEnabled( false );
92
93          // create DisconnectListener for disconnect buttons
94          ActionListener disconnectListener =
95             new DisconnectListener();
96          disconnectButton.addActionListener( disconnectListener );
97          disconnectMenuItem.addActionListener( disconnectListener );
98
99          // add connect and disconnect JMenuItems to fileMenu
100         serverMenu.add( connectMenuItem );
101         serverMenu.add( disconnectMenuItem );
102
103         // add connect and disconnect JButtons to buttonPanel
104         JPanel buttonPanel = new JPanel();
105         buttonPanel.add( connectButton );
106         buttonPanel.add( disconnectButton );
107
108         // create JTextArea for displaying messages
109         messageArea = new JTextArea();
110
111         // disable editing and wrap words at end of line
112         messageArea.setEditable( false );
113         messageArea.setWrapStyleWord( true );
114         messageArea.setLineWrap( true );
115
116         // put messageArea in JScrollPane to enable scrolling
117         JPanel messagePanel = new JPanel();
118         messagePanel.setLayout( new BorderLayout( 10, 10 ) );
119         messagePanel.add( new JScrollPane( messageArea ),
120            BorderLayout.CENTER );
121
122         // create JTextArea for entering new messages
123         inputArea = new JTextArea( 4, 20 );
124         inputArea.setWrapStyleWord( true );
125         inputArea.setLineWrap( true );
126         inputArea.setEditable( false );
127
128         // create Icon for sendButton
129         Icon sendIcon = new ImageIcon(
130            getClass().getResource( "images/Send.gif" ) );
131
132         // create sendButton and disable it
133         sendButton = new JButton( "Send", sendIcon );
134         sendButton.setEnabled( false );
135
136         // create ActionListener for sendButton
137         sendButton.addActionListener(
138            new ActionListener() {
139
```

Fig. 17.20 **`ClientGUI`** subclass of **`JFrame`** for presenting a GUI for viewing and sending chat messages (part 3 of 6).

```
140             // send new message when user activates sendButton
141             public void actionPerformed( ActionEvent event )
142             {
143                messageManager.sendMessage( userName,
144                   inputArea.getText());
145
146                // clear inputArea
147                inputArea.setText( "" );
148             }
149          } // end ActionListener
150       );
151
152       // lay out inputArea and sendButton in BoxLayout and
153       // add Box to messagePanel
154       Box box = new Box( BoxLayout.X_AXIS );
155       box.add( new JScrollPane( inputArea ) );
156       box.add( sendButton );
157       messagePanel.add( box, BorderLayout.SOUTH );
158
159       // create JLabel for statusBar with a recessed border
160       statusBar = new JLabel( "Not Connected" );
161       statusBar.setBorder(
162          new BevelBorder( BevelBorder.LOWERED ) );
163
164       // lay out components in JFrame
165       Container container = getContentPane();
166       container.add( buttonPanel, BorderLayout.NORTH );
167       container.add( messagePanel, BorderLayout.CENTER );
168       container.add( statusBar, BorderLayout.SOUTH );
169
170       // add WindowListener to disconnect when user quits
171       addWindowListener (
172          new WindowAdapter () {
173
174             // disconnect from server and exit application
175             public void windowClosing ( WindowEvent event )
176             {
177                messageManager.disconnect( messageListener );
178                System.exit( 0 );
179             }
180          }
181       );
182
183    } // end ClientGUI constructor
184
185    // ConnectListener listens for user requests to connect to
186    // DeitelMessengerSever
187    private class ConnectListener implements ActionListener {
188
189       // connect to server and enable/disable GUI components
190       public void actionPerformed( ActionEvent event )
191       {
```

Fig. 17.20 **`ClientGUI`** subclass of **`JFrame`** for presenting a GUI for viewing and sending chat messages (part 4 of 6).

```
192          // connect to server and route messages to
193          // messageListener
194          messageManager.connect( messageListener );
195
196          // prompt for userName
197          userName = JOptionPane.showInputDialog(
198             ClientGUI.this, "Enter user name:" );
199
200          // clear messageArea
201          messageArea.setText( "" );
202
203          // update GUI components
204          connectButton.setEnabled( false );
205          connectMenuItem.setEnabled( false );
206          disconnectButton.setEnabled( true );
207          disconnectMenuItem.setEnabled( true );
208          sendButton.setEnabled( true );
209          inputArea.setEditable( true );
210          inputArea.requestFocus();
211          statusBar.setText( "Connected: " + userName );
212       }
213
214    } // end ConnectListener inner class
215
216    // DisconnectListener listens for user requests to disconnect
217    // from DeitelMessengerServer
218    private class DisconnectListener implements ActionListener {
219
220       // disconnect from server and enable/disable GUI components
221       public void actionPerformed( ActionEvent event )
222       {
223          // disconnect from server and stop routing messages
224          // to messageListener
225          messageManager.disconnect( messageListener );
226
227          // update GUI componets
228          sendButton.setEnabled( false );
229          disconnectButton.setEnabled( false );
230          disconnectMenuItem.setEnabled( false );
231          inputArea.setEditable( false );
232          connectButton.setEnabled( true );
233          connectMenuItem.setEnabled( true );
234          statusBar.setText( "Not Connected" );
235       }
236
237    } // end DisconnectListener inner class
238
239    // MyMessageListener listens for new messages from the
240    // MessageManager and displays the messages in messageArea
241    // using a MessageDisplayer.
242    private class MyMessageListener implements MessageListener {
243
```

Fig. 17.20 **`ClientGUI`** subclass of **`JFrame`** for presenting a GUI for viewing and sending chat messages (part 5 of 6).

```
244         // when received, display new messages in messageArea
245         public void messageReceived( String from, String message )
246         {
247            // append message using MessageDisplayer and
248            // invokeLater, ensuring thread-safe access messageArea
249            SwingUtilities.invokeLater(
250               new MessageDisplayer( from, message ) );
251
252         } // end method messageReceived
253
254      }  // end MyMessageListener inner class
255
256      // MessageDisplayer displays a new messaage by
257      // appending the message to the messageArea JTextArea. This
258      // Runnable object should be executed only on the Event
259      // thread, because it modifies a live Swing component.
260      private class MessageDisplayer implements Runnable {
261
262         private String fromUser;
263         private String messageBody;
264
265         // MessageDisplayer constructor
266         public MessageDisplayer( String from, String body )
267         {
268            fromUser = from;
269            messageBody = body;
270         }
271
272         // display new message in messageArea
273         public void run()
274         {
275            // append new message
276            messageArea.append( "\n" + fromUser + "> " +
277               messageBody );
278
279            // move caret to end of messageArea to ensure new
280            // message is visible on screen
281            messageArea.setCaretPosition(
282              messageArea.getText().length() );
283         }
284
285      } // end MessageDisplayer inner class
286   }
```

Fig. 17.20 **`ClientGUI`** subclass of **`JFrame`** for presenting a GUI for viewing and sending chat messages (part 6 of 6).

`ClientGUI` uses a **`MessageManager`** (line 41) to handle all communication with the chat server. Recall that **`MessageManager`** is an interface and therefore allows **`ClientGUI`** to use any **`MessageManager`** implementation without the need to change any code in **`ClientGUI`**. Class **`ClientGUI`** also uses a **`MessageListener`** (line 44) to receive incoming messages from the **`MessageManager`**.

The **`ClientGUI`** constructor (lines 47–183) takes as an argument the **`MessageManager`** for communicating with **`DeitelMessengerServer`**. Line 52 sets the **`Cli-`**

entGUI's **MessageManager**. Line 55 creates an instance of **MyMessageListener**, which implements interface **MessageListener**. Lines 58–62 create a **Server** menu that contains **JMenuItem**s for connecting to and disconnecting from the chat server. Lines 65–66 create an **ImageIcon** for **connectButton** and **connectMenuItem**.

Line 66 invokes method **getClass** (inherited from class **Object**) to retrieve the **Class** object that represents the **ClientGUI** class definition. Line 66 then invokes method ***getResource*** of class **Class** to load the connect image. The Java virtual machine loads class definitions into memory, using a *class loader*. Method **getResource** of **Class** uses the **Class** object's class loader to specify the location of a resource, such as an image file. Specifying resource locations in this manner enables programs to avoid hard-coded or absolute paths, which can make programs more difficult to deploy. Using the techniques described here enables an applet or application to load files from locations that are relative to the location of the **.class** file for a given class.

Lines 69–70 create **connectButton** and **connectMenuItem**, each with the label **"Connect"** and the **Icon connectIcon**. Line 71 invokes method **setMnemonic** of class **JMenuItem** to set the mnemonic character for keyboard access to **connectMenuItem**. Line 74 creates an instance of **private** inner class **ConnectListener**, which implements interface **ActionListener** to handle **ActionEvent**s from **connectButton** and **connectMenuItem**. Lines 75–76 add **connectListener** as an **ActionListener** for **connectButton** and **connectMenuItem**.

Lines 79–80 create an **ImageIcon** for the **disconnectButton** and **disconnectMenuItem** components. Lines 83–86 create **disconnectButton** and **disconnectMenuItem**, each with the label **"Disconnect"** and the **Icon disconnectIcon**. Line 87 invokes method **setMnemonic** of class **JMenuItem** to enable keyboard access to **disconnectMenuItem**. Lines 90–91 invoke method **setEnabled** of class **JButton** and class **JMenuItem** with a **false** argument to disable **disconnectButton** and **disconnectMenuItem**. This prevents the user from attempting to disconnect from the server because the client is not yet connected. Lines 94–95 create an instance of **private** inner class **DisconnectListener**, which implements interface **ActionListener** to handle **ActionEvent**s from **disconnectButton** and **disconnectMenuItem**. Lines 96–97 add **disconnectListener** as an **ActionListener** for the **disconnectButton** and **disconnectMenuItem** components.

Lines 100–101 add **connectMenuItem** and **disconnectMenuItem** to the **Server JMenu**. Lines 104–106 create a **JPanel** and add **connectButton** and **disconnectButton** to that **JPanel**. Line 109 creates the **JTextArea messageArea**, in which the client displays incoming messages. Line 112 invokes method **setEnabled** with a **false** argument, to disable editing ot the text in **messageArea**. Lines 113–114 invoke methods **setWrapStyleWord** and **setLineWrap** of class **JTextArea** to enable word wrapping in **messageArea**. If a message is longer than the width of the **messageArea**, the **messageArea** will wrap the text after the last word that fits on each line, making longer messages easier to read. Lines 117–120 create a **JPanel** for the **messageArea** and add the **messageArea** to the **JPanel** in a **JScrollPane**. The **JScrollPane** adds scroll bars to the **messageArea** to enable the user to scroll through messages that exceed the size of **messageArea**.

Line 123 creates the **inputArea JTextArea** for entering new messages. The arguments to the **JTextArea** constructor specify a four-line **JTextArea** that is twenty char-

acters wide. Lines 124–125 enable word and line wrapping, and line 126 disables editing the **inputArea**. When the client connects to the chat server, **ConnectListener** enables the **inputArea** to allow the user to type new messages.

Line 129 creates an **ImageIcon** for **sendButton**. Line 133 creates **sendButton**, which the user can click to send a message the user has typed. Line 134 disables **sendButton**; the **ConnectListener** enables the **sendButton** when the client connects to the chat server. Lines 137–150 add an **ActionListener** to **sendButton**. Lines 143–144 invoke method **sendMessage** of interface **MessageManager** with the **userName** and **inputArea** text as arguments. This statement sends the user's name and whatever text the user entered in **inputArea** to **DeitelMessengerServer** as a new chat message. Line 147 invokes method **setText** of class **JTextArea** with an empty **String** argument to clear the **inputArea** for the next message.

Lines 154–157 use a **BoxLayout** to arrange the **inputArea** and **sendButton**. Line 155 places **inputArea** in a **JScrollPane** to enable scrolling of long messages. Line 157 adds the **Box** containing **inputArea** and **sendButton** to the **SOUTH** region of **messagePanel**. Lines 160–162 create the **statusBar** **JLabel**. This **JLabel** displays whether the client is connected to or disconnected from the chat server. Lines 161–162 invoke method **setBorder** of class **JLabel** and create a new **BevelBorder** of type **BevelBorder.LOWERED**. This border makes the **JLabel** appear recessed, as is common with status bars in many applications. Lines 165–168 lay out **buttonPanel**, **messagePanel** and **statusBar** in the **ClientGUI** **JFrame**.

Lines 171–181 add a **WindowListener** to the **ClientGUI** **JFrame**. Line 177 invokes method **disconnect** of interface **MessageManager** to disconnect from the chat server in case the user quits while still connected.

Inner class **ConnectListener** (lines 187–214) handles events from **connectButton** and **connectMenuItem**. Line 194 invokes method connect of class **MessageManager** to connect to the chat server. Line 194 passes as an argument to method **connect** the **MessageListener** to which new messages should be delivered. Lines 197-198 prompt the user for a user name, and line 201 clears the **messageArea** **JTextArea**. Lines 204–209 enable the components for disconnecting from the server and for sending messages and disable components for connecting to the server. Line 210 invokes method **requestFocus** of class **JTextArea** to place the text-input cursor in the **inputArea** so the user can begin typing a message more easily.

Inner class **DisconnectListener** (lines 218–237) handles events from **disconnectButton** and **disconnectMenuItem**. Line 225 invokes method **disconnect** of class **MessageManager** to disconnect from the chat server. Lines 228–234 disable the components for sending messages and the components for disconnecting then enable the components for connecting to the chat server.

Inner class **MyMessageListener** (lines 242–254) implements interface **MessageListener** to receive incoming messages from the **MessageManager**. When a new message is received, the program invokes method **messageReceived** (lines 242–252) with the user name of the sender and the message body. Lines 249–250 invoke **static** method **invokeLater** of class **SwingUtilties** with a new instance of **MessageDisplayer** to append the new message to **messageArea**. Recall, from Chapter 15, that Swing components should be accessed only from the event dispatching thread. Method **messageReceived** is invoked by the **PacketReceivingThread** in

class **SocketMessageManager** and therefore cannot append the message text to **messageArea** directly, as this would occur in **PacketReceivingThread**, not the event-dispatch thread.

Inner class **MessageDisplayer** (lines 260–285) implements interface **Runnable** to provide a thread-safe way to append text to the **messageArea JTextArea**. The **MessageDisplayer** constructor (lines 266–270) takes as arguments the user name and message to send. Method **run** (lines 273–283) appends the user name, **"> "** and **messageBody** to **messageArea**. Lines 281–282 invoke method **setCaretPosition** of class **JTextArea** to scroll **messageArea** to the bottom to display the most recently received message. Instances of class **MessageDisplayer** should execute only as part of the event-dispatching thread, to ensure thread-safe access to the **messageArea** Swing component.

Class **DeitelMessenger** (Fig. 17.21) launches the client for the **DeitelMessengerServer**. Lines 18–21 create a new **SocketMessageManager** to connect to the **DeitelMessengerServer** with the IP address specified as a command-line argument to the application. Lines 24–27 create a **ClientGUI** for the **MessageManager**, set the **ClientGUI** size and make the **ClientGUI** visible.

```
1  // DeitelMessenger.java
2  // DeitelMessenger is a chat application that uses a ClientGUI
3  // and SocketMessageManager to communicate with
4  // DeitelMessengerServer.
5  package com.deitel.messenger.sockets.client;
6
7  // Deitel packages
8  import com.deitel.messenger.*;
9
10 public class DeitelMessenger {
11
12    // execute application
13    public static void main( String args[] )
14    {
15       MessageManager messageManager;
16
17       // create new DeitelMessenger
18       if ( args.length == 0 )
19          messageManager = new SocketMessageManager( "localhost" );
20       else
21          messageManager = new SocketMessageManager( args[ 0 ] );
22
23       // create GUI for SocketMessageManager
24       ClientGUI clientGUI = new ClientGUI( messageManager );
25       clientGUI.setSize( 300, 400 );
26       clientGUI.setResizable( false );
27       clientGUI.setVisible( true );
28    }
29 }
```

Fig. 17.21 **DeitelMessenger** application for participating in a **DeitelMessengerServer** chat session (part 1 of 3).

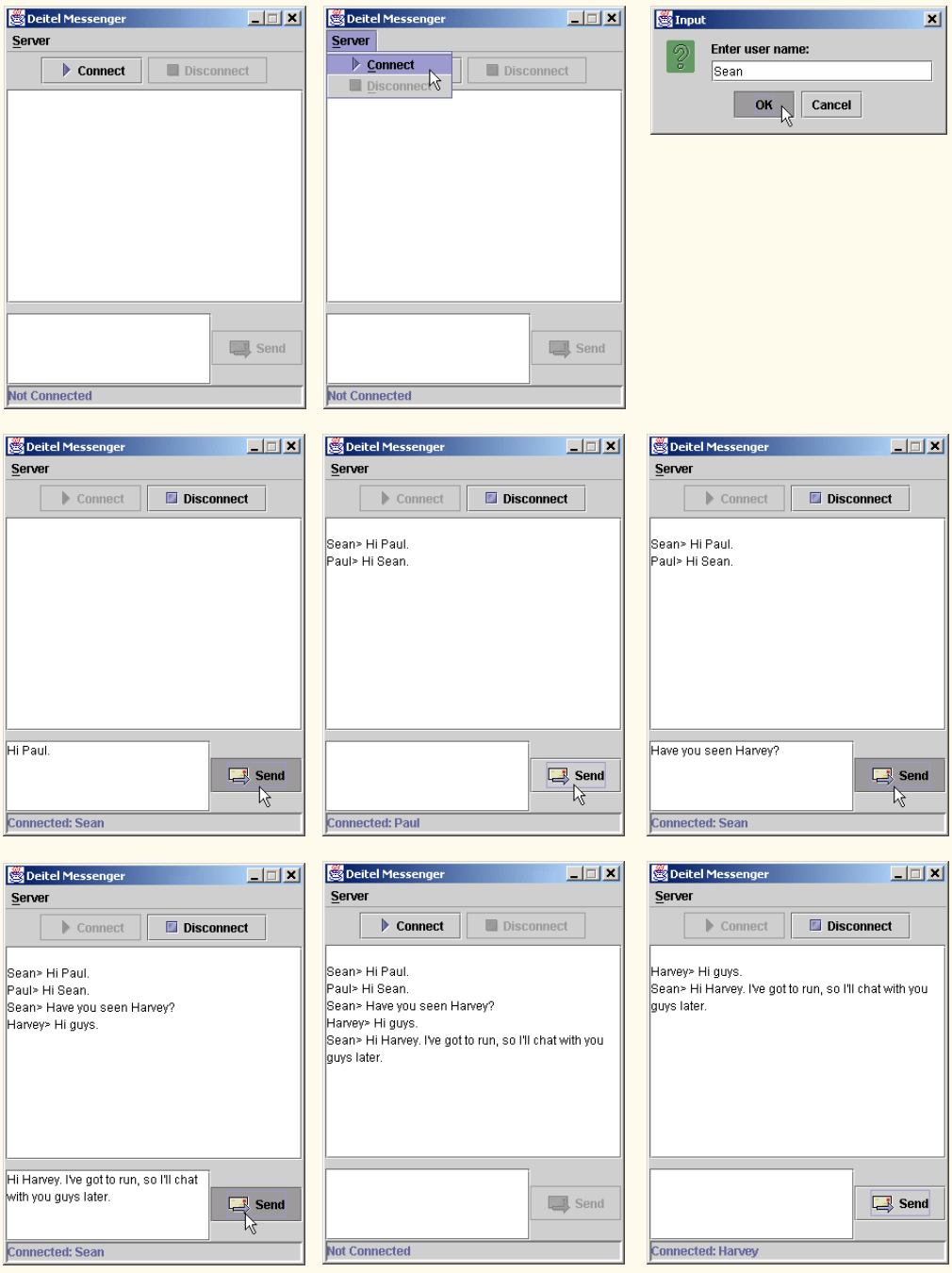


Fig. 17.21 **`DeitelMessenger`** application for participating in a **`DeitelMessengerServer`** chat session (part 2 of 3).

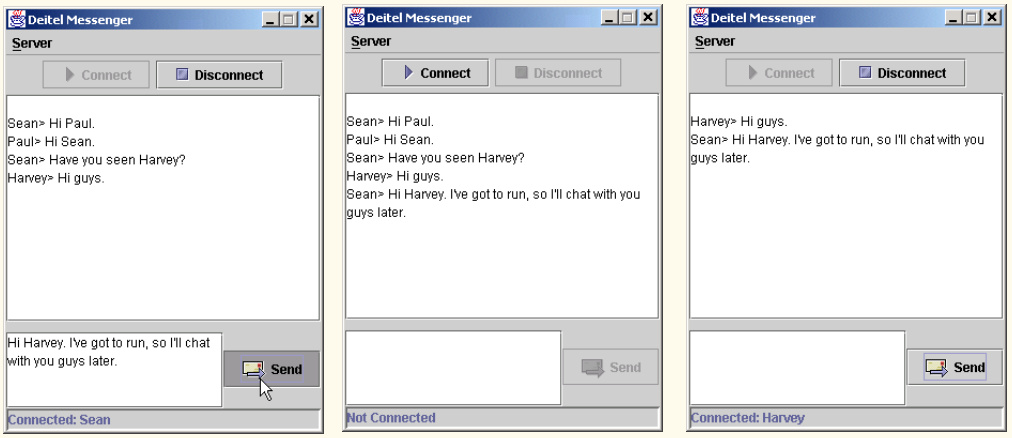


Fig. 17.21 **`DeitelMessenger`** application for participating in a **`DeitelMessengerServer`** chat session (part 3 of 3).

The Deitel messenger case study is a significant application that uses many intermediate Java features, such as networking with **`Socket`**s, **`DatagramPacket`**s and **`MulticastSocket`**s, multithreading and Swing GUI. The case study also demonstrates good software engineering practices by separating interface from implementation, enabling developers to build **`MessageManager`**s for different network protocols and **`MessageListener`**s that provide different user interfaces. You should now be able to apply these techniques to your own, more complex, Java projects.

17.11 (Optional) Discovering Design Patterns: Design Patterns Used in Packages `java.io` and `java.net`

This section introduces those design patterns associated with the Java file, streams and networking packages.

17.11.1 Creational Design Patterns

We now continue our discussion of creational design patterns.

Abstract Factory

Like the Factory Method design pattern, the *Abstract Factory design pattern* allows a system to determine the subclass from which to instantiate an object at run time. Often, this subclass is unknown during development. However, Abstract Factory uses an object known as a *factory* that uses an interface to instantiate objects. A factory creates a product; in this case, that product is an object of a subclass determined at run time.

The Java socket library in package **`java.net`** uses the Abstract Factory design pattern. A socket describes a connection, or a stream of data, between two computers. Class **`Socket`** references an object of a **`SocketImpl`** subclass (Section 17.5). Class **`Socket`** also contains a **`static`** reference to an object implementing interface **`SocketImplFactory`**. The **`Socket`** constructor invokes method **`createSocketImpl`** of interface **`SocketFactory`** to create the **`SocketImpl`** object. The object that imple-

ments interface **SocketFactory** is the factory, and an object of a **SocketImpl** subclass is the product of that factory. The system cannot specify the **SocketImpl** subclass from which to instantiate until run time, because the system has no knowledge of what type of **Socket** implementation is required (e.g., a socket configured to the local network's security requirements). Method **createSocketImpl** decides the **SocketImpl** subclass from which to instantiate the object at run time.

17.11.2 Structural Design Patterns

This section concludes our discussion of structural design patterns.

Decorator

Let us reexamine class **CreateSequentialFile** (Fig. 16.6). Lines 127–128 of this class allow an **ObjectOutputStream** object, which writes objects to a file, to gain the responsibilities of a **FileOutputStream** object, which provides methods for writing **byte**s to files. Class **CreateSequentialFile** appears to "chain" objects—a **FileOutputStream** object is the argument to the **ObjectOutputStream**'s constructor. The fact that the **ObjectOutputStream** object can gain the behavior of a **FileOutputStream** dynamically prevents the need for creating a separate class called **ObjectFileOutputStream**, which would implement the behaviors of both classes.

Lines 127–128 of class **CreateSequentialFile** show an example of the *Decorator design pattern*, which allows an object to gain additional responsibilities dynamically. Using this pattern, designers do not have to create separate, unnecessary classes to add responsibilities to objects of a given class.

Let us consider a more complex example to discover how the Decorator design pattern can simplify a system's structure. Suppose we wanted to enhance the I/O-performance of the previous example by using a **BufferedOutputStream**. Using the Decorator design pattern, we would write

```
output = new ObjectOutputStream(
   new BufferedOutputStream(
      new FileOutputStream( fileName ) ) );
```

We can chain objects in this manner, because **ObjectOutputStream**, **BufferedOutputStream** and **FileOutputStream** extend abstract superclass **OutputStream**, and each subclass constructor takes an **OutputStream** object as a parameter. If the stream objects in package **java.io** did not use the Decorator pattern (i.e., did not satisfy these two requirements), package **java.io** would have to provide classes **BufferedFileOutputStream**, **ObjectBufferedOutputStream**, **ObjectBufferedFileOutputStream** and **ObjectFileOutputStream**. Consider how many classes we would have to create if we chained even more stream objects without applying the Decorator pattern.

Facade

When driving a car, you know that pressing the gas pedal accelerates your car, but you are unaware of exactly how the gas pedal causes your car to accelerate. This principle is the foundation of the *Facade design pattern*, which allows an object—called a *facade object*—to provide a simple interface for the behaviors of a *subsystem*—an aggregate of objects that comprise collectively a major system responsibility. The gas pedal, for example, is the facade object for the car's acceleration subsystem, the steering wheel is the facade object for

the car's steering subsystem and the brake is the facade object for the car's deceleration subsystem. A *client object* uses the facade object to access the objects behind the facade. The client remains unaware of how the objects behind the facade fulfill responsibilities, so the subsystem complexity is hidden from the client. When you press the gas pedal you act as a client object. The Facade design pattern reduces system complexity, because a client interacts with only one object (the facade). This pattern shields applications developers from subsystem complexities. Developers need to be familiar with only the operations of the facade object, rather than with the more detailed operations of the entire subsystem.

In package **`java.net`**, an object of class **`URL`** is a facade object. This object contains a reference to an **`InetAddress`** object that specifies the host computer's IP address. The URL facade object also references an object from class **`URLStreamHandler`**, which opens the URL connection. The client object that uses the **`URL`** facade object accesses the **`InetAddress`** object and the **`URLStreamHandler`** object through the facade object. However, the client object does not know how the objects behind the **`URL`** facade object accomplish their responsibilities.

17.11.3 Architectural Patterns

Design patterns allow developers to design specific parts of systems, such as abstracting object instantiations or aggregating classes into larger structures. Design patterns also promote loose coupling among objects. *Architectural patterns* promote loose coupling among subsystems. These patterns specify all subsystems in the system and how they interact with each other.[1] We introduce the popular Model-View-Controller and Layers architectural patterns.

MVC

Consider the design of a simple text editor. In this program, the user inputs text from the keyboard and formats this text using the mouse. Our program stores this text and format information into a series of data structures, then displays this information on screen for the user to read what has been inputted.

This program adheres to the *Model-View-Controller* (MVC) *architectural pattern*, which separates application data (contained in the *model*) from graphical presentation components (the *view*) and input-processing logic (the *controller*).[2] Figure 17.22 shows the relationships between components in MVC.

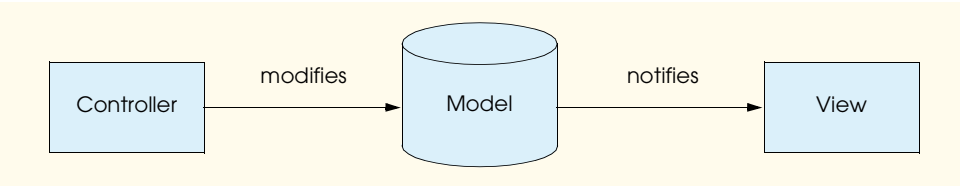


Fig. 17.22 Model-View-Controller Architecture.

1. R. Hartman. "Building on Patterns." *Application Development Trends* May 2001: 19–26.
2. Section 13.17 also discussed Model-View-Controller architecture and its relevance to the elevator simulation case study.

The controller implements logic for processing user inputs. The model contains application data, and the view presents the data stored in the model. When a user provides some input, the controller modifies the model with the given input. The model contains the application data. With regards to the text-editor example, the model might contain only the characters that make up the document. When the model changes, it notifies the view of the change so the view can update its presentation with the changed data. The view in a word processor might display characters using a particular font, with a particular size, etc.

MVC does not restrict an application to a single view and a single controller. In a more sophisticated program (e.g., a word processor), there might be two views of a document model. One view might display an outline of the document and the other might display the complete document. The word processor also might implement multiple controllers—one for handling keyboard input and another for handling mouse selections. If either controller makes a change in the model, both the outline view and the print-preview window will show the change immediately when the model notifies all views of changes.

Another key benefit to the MVC architectural pattern is that developers can modify each component individually without having to modify the other components. For example, developers could modify the view that displays the document outline, but the developers would not have to modify either the model or other views or controllers.

Layers

Consider the design in Fig. 17.23, which presents the basic structure of a *three-tier application*, in which each tier contains a unique system component.

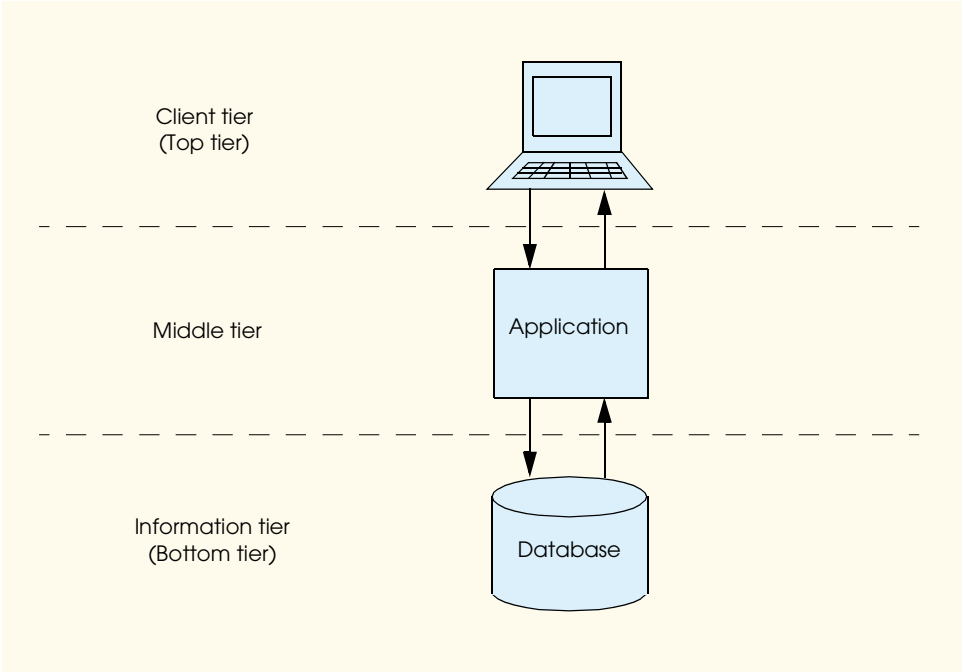


Fig. 17.23 Three-tier application model.

The *information tier* (also called the "bottom tier") maintains data for the application, typically storing the data in a database. The information tier for an online store may contain product information, such as descriptions, prices and quantities in stock and customer information, such as user names, billing addresses and credit-card numbers.

The *middle tier* acts as an intermediary between the information tier and the client tier. The middle tier processes client-tier requests, reads data from and writes data to the database. The middle tier then processes data from the information tier and presents the content to the client tier. This processing is the application's *business logic*, which handles such tasks as retrieving data from the information tier, ensuring that data is reliable before updating the database and presenting data to the client tier. For example, the business logic associated with the middle tier for the online store can verify a customer's credit card with the credit-card issuer before the warehouse ships the customer's order. This business logic could then store (or retrieve) the credit information in the database and notify the client tier that the verification was successful.

The *client tier* (also called the "top tier") is the application's user interface, such as a standard Web browser. Users interact directly with the application through the user interface. The client tier interacts with the middle tier to make requests and retrieve data from the information tier. The client tier then displays data retrieved from the middle tier.

Figure 17.23 is an implementation of the *Layers architectural pattern*, which divides functionality into separate *layers*. Each layer contains a set of system responsibilities and depends on the services of only the next lower layer. In Fig. 17.23, each tier corresponds to a layer. This architectural pattern is useful, because a designer can modify one layer without having to modify the other layers. For example, a designer could modify the information tier in Fig. 17.23 to accommodate a particular database product, but the designer would not have to modify either the client tier or the middle tier.

17.11.4 Conclusion

In this "Discovering Design Patterns" section, we discussed how packages **`java.io`** and **`java.net`** take advantage of specific design patterns and how developers can integrate design patterns with networking/file applications in Java. We also introduced the Model-View-Controller and Layers architectural patterns, which both assign system functionality to separate subsystems. These patterns make designing a system easier for developers. In "Discovering Design Patterns" Section 21.12, we conclude our presentation of design patterns by discussing those design patterns used in package **`java.util`**.

SUMMARY

- Java provides stream sockets and datagram sockets. With stream sockets, a process establishes a connection to another process. While the connection is in place, data flows between the processes in continuous streams. Stream sockets are said to provide a connection-oriented service. The protocol used for transmission is the popular TCP (Transmission Control Protocol).
- With datagram sockets, individual packets of information are transmitted. This is not the right protocol for everyday users, because, unlike TCP, the protocol used, UDP—the User Datagram Protocol—is a connectionless service and does not guarantee that packets arrive in any particular way. In fact, packets can be lost, can be duplicated and can even arrive out of sequence. So, with UDP, significant extra programming is required on the user's part to deal with these problems (if the user chooses to do so).

- The HTTP protocol (Hypertext Transfer Protocol) that forms the basis of the World Wide Web uses URIs (Uniform Resource Identifiers, also called URLs or Uniform Resource Locators) to locate data on the Internet. Common URIs represent files or directories and can represent complex tasks such as database lookups and Internet searches.
- Web browsers often restrict an applet so that it can communicate only with the machine from which it was originally downloaded.
- A **`Hashtable`** stores key/value pairs. A program uses a key to store and retrieve an associated value in the **`Hashtable`**. **`Hashtable`** method **`put`** takes two arguments—a key and its associated value—and places the value in the **`Hashtable`** at a location determined by the key. **`Hashtable`** method **`get`** takes one argument—a key—and retrieves the value (as an **`Object`** reference) associated with the key.
- A **`Vector`** is a dynamically resizable array of **`Object`**s. **`Vector`** method **`addElement`** adds a new element to the end of the **`Vector`**.
- **`Applet`** method **`getAppletContext`** returns a reference to an **`AppletContext`** object that represents the applet's environment (i.e., the browser in which the applet is executing).
- **`AppletContext`** method **`showDocument`** receives a **`URL`** object as an argument and passes it to the **`AppletContext`** (i.e., the browser), which displays the World Wide Web resource associated with that **`URL`**.
- A second version of **`AppletContext`** method **`showDocument`** enables an applet to specify the target frame in which Web resource should be displayed. Special target frames include **`_blank`** (display the content from the specified URI in a new Web browser window), **`_self`** (display the content from the specified URI in the same frame as the applet) and **`_top`** (the browser should remove the current frames, then display the content from the specified URI in the current window).
- **`Component`** method **`setCursor`** changes the mouse cursor when the cursor is positioned over a specific GUI component. The **`Cursor`** constructor receives an integer indicating the cursor type (such as **`Cursor.WAIT_CURSOR`** or **`Cursor.DEFAULT_CURSOR`**).
- **`JEditorPane`** method **`setPage`** downloads the document specified by its argument and displays it in the **`JEditorPane`**.
- Typically, an HTML document contains hyperlinks—text, images or GUI components that, when clicked, link to another document on the Web. If an HTML document is displayed in a **`JEditorPane`** and the user clicks a hyperlink, the **`JEditorPane`** generates a **`HyperlinkEvent`** (package **`javax.swing.event`**) and notifies all registered **`HyperlinkListener`**s (package **`javax.swing.event`**) of that event.
- **`HyperlinkEvent`** method **`getEventType`** determines the type of the **`HyperlinkEvent`**. Class **`HyperlinkEvent`** contains **`public static`** inner class **`EventType`**, which defines three hyperlink event types: **`ACTIVATED`** (user clicked a hyperlink), **`ENTERED`** (user moved the mouse over a hyperlink) and EXITED (user moved the mouse away from a hyperlink).
- **`HyperlinkEvent`** method **`getURL`** obtains the **`URL`** represented by the hyperlink.
- Stream-based connections are managed with **`Socket`** objects.
- A **`ServerSocket`** object establishes the port where a server waits for connections from clients. The second argument to the **`ServerSocket`** constructor specifies the number of clients that can wait for a connection and be processed by the server. If the queue of clients is full, client connections are refused. The **`ServerSocket`** method **`accept`** waits indefinitely (i.e., blocks) for a connection from a client and returns a **`Socket`** object when a connection is established.
- **`Socket`** method **`getOutputStream`** gets a reference to the **`OutputStream`** associated with a **`Socket`**. **`Socket`** method **`getInputStream`** gets a reference to the **`InputStream`** associated with the **`Socket`**.

- When transmission over a **Socket** connection is complete, the server closes the connection by invoking the **Socket**'s **close** method.
- A **Socket** object connects a client to a server by specifying the server name and port number when creating the **Socket** object. A failed connection attempt throws an **IOException**.
- When the **InputStream** method **read** returns **-1**, the stream detects that the end-of-stream has been reached.
- An **EOFException** occurs when a **ObjectInputStream** attempts to read a value from a stream on which end-of-stream is detected.
- **InetAddress** method **getByName** returns an **InetAddress** object containing the host name of the computer for which the **String** host name or **String** Internet address is specified as an argument.
- **InetAddress** method **getLocalHost** returns an **InetAddress** object containing the host name of the local computer executing the program.
- The port at which a client connects to a server is sometimes called the handshake point.
- Connection-oriented transmission is like the telephone system—you dial and are given a connection to the telephone of the person with whom you wish to communicate. The connection is maintained for the duration of your phone call, even when you are not talking.
- Connectionless transmission with datagrams is similar to mail carried via the postal service. A large message that will not fit in one envelope can be broken into separate message pieces that are placed in separate, sequentially numbered envelopes. Each of the letters is then mailed at once. The letters could arrive in order, out of order or not at all.
- **DatagramPacket** objects store packets of data for sending or store packets of data received by an application. **DatagramSocket**s send and receive **DatagramPacket**s.
- The **DatagramSocket** constructor that takes no arguments binds the application to a port chosen by the computer on which the program executes. The **DatagramSocket** constructor that takes an integer port number argument binds the application to the specified port. If a **DatagramSocket** constructor fails to bind the application to a port, a **SocketException** occurs.
- **DatagramSocket** method **receive** blocks (waits) until a packet arrives, then stores the packet in its argument.
- **DatagramPacket** method **getAddress** returns an **InetAddress** object containing information about the host computer from which the packet was sent.
- **DatagramPacket** method **getPort** returns an integer specifying the port number through which the host computer sent the **DatagramPacket**.
- **DatagramPacket** method **getLength** returns an integer representing the number of bytes of data in a **DatagramPacket**.
- **DatagramPacket** method **getData** returns a byte array containing the data in a **DatagramPacket**.
- The **DatagramPacket** constructor for a packet to be sent takes four arguments—the byte array to be sent, the number of bytes to be sent, the client address to which the packet will be sent and the port number where the client is waiting to receive packets.
- **DatagramSocket** method send sends a **DatagramPacket** out over the network.
- If an error occurs when receiving or sending a **DatagramPacket**, an **IOException** occurs.
- Reading data from a **Socket** is a blocking call—the current thread is put in the blocked state while the thread waits for the read operation to complete. Method **setSoTimeout** specifies that, if no data is received in the given number of milliseconds, the **Socket** should issue an **Inter-**

ruptedIOException, which the current thread can catch, then continue executing. This prevents the current thread from deadlocking if there is no more data available from the **Socket**.

- Multicast is an efficient way to send data to many clients without the overhead of broadcasting that data to every host on the Internet.
- Using multicast, an application can "publish" **DatagramPacket**s to be delivered to other applications—the "subscribers."
- An application multicasts **DatagramPacket**s by sending the **DatagramPacket**s to a multicast address—an IP address in the range from 224.0.0.0 to 239.255.255.255, reserved for multicast.
- Clients that wish to receive **DatagramPacket**s can connect to the multicast address to join the multicast group that will receive the published **DatagramPacket**s.
- Multicast **DatagramPacket**s are not reliable—packets are not guaranteed to reach any destination. Also, the order in which clients receive the datagrams is not guaranteed.
- The **MulticastSocket** constructor takes as an argument the port to which the **MulticastSocket** should connect to receive incoming **DatagramPacket**s. Method **joinGroup** of class **MulticastSocket** takes as an argument the **InetAddress** of the multicast group to join.
- Method receive of class **MulticastSocket** reads an incoming **DatagramPacket** from a multicast address.

TERMINOLOGY

accept a connection
accept method of **ServerSocket** class
addElement method of class **Vector**
AppletContext interface
bind to a port
BindException class
client
client connects to a server
client/server relationship
client-side socket
close a connection
close method of class **Socket**
collaborative computing
computer networking
connect to a port
connect to a World Wide Web site
ConnectException class
connection
connection request
connectionless service
connectionless transmission with datagrams
connection-oriented service
Cursor class
Cursor.DEFAULT_CURSOR
Cursor.WAIT_CURSOR
datagram
datagram socket
DatagramPacket class
DatagramSocket class
deny a connection
duplicated packets
get method of class **Hashtable**
getAddress method of **DatagramPacket**
getAppletContext method of class **Applet**
getByName method of **InetAddress**
getData method of class **DatagramPacket**
getEventType method
getInputStream method of class **Socket**
getLength method of **DatagramPacket**
getLocalHost method
getLocalHost method of **InetAddress**
getOutputStream method of class **Socket**
getPort method of class **DatagramPacket**
getPredefinedCursor method of Cursor
getURL method of class **HyperlinkEvent**
handshake point
Hashtable class
heterogeneous computer systems
host
Hyperlink.EventType class
Hyperlink.EventType.ACTIVATED
Hyperlink.EventType.ENTERED
Hyperlink.EventType.EXITED
HyperlinkEvent class
HyperlinkListener interface
hyperlinkUpdate method
InetAddress class
Internet

Internet address
InterruptedIOException class
IOException class
Java Security API
java.net package
JEditorPane class
joinGroup method of **MulticastSocket**
key/value pair
leaveGroup method of **MulticastSocket**
lost packets
MalformedURLException class
multicast
multicast address
multicast group
MulticastSocket class
multithreaded server
network programming
networking
open a socket
out-of-sequence packets
packet
packet length
port
port number on a server
put method of class **Hashtable**
read from a socket
receive method of class **DatagramSocket**
register an available port number
send method of class **DatagramSocket**
server
server-side socket
ServerSocket class
setCursor method of class **Component**
setPage method of class **JEditorPane**
setSoTimeout method of class **Socket**
showDocument method of **AppletContext**
socket
Socket class
socket-based communications
SocketException
stream socket
TCP (Transmission Control Protocol)
UDP (User Datagram Protocol)
UnknownHostException
URI (Uniform Resource Identifier)
URL (Uniform Resource Locator)
URL class
Vector class
wait for a connection
wait for a packet
Web browser
Web server
World Wide Web

SELF-REVIEW EXERCISES

17.1 Fill in the blanks in each of the following statements:

a) Exception _____ occurs when an input/output error occurs when closing a socket.
b) Exception _____ occurs when a server address indicated by a client cannot be resolved.
c) If a **DatagramSocket** constructor fails to set up a **DatagramSocket** properly, an exception of type _____ occurs.
d) Many of Java's networking classes are contained in package _____.
e) Class _____ binds the application to a port for datagram transmission.
f) An object of class _____ contains an Internet address.
g) The two types of sockets we discussed in this chapter are _____ sockets and _____ sockets.
h) The acronym URL stands for _____.
i) The acronym URI stands for _____.
j) The key protocol that forms the basis of the World Wide Web is _____.
k) **AppletContext** method _____ receives a **URL** object as an argument and displays in a browser the World Wide Web resource associated with that **URL**.
l) **InetAddress** method **getLocalHost** returns an _____ object containing the local host name of the computer on which the program is executing.
m) Method _____ of class **MulticastSocket** subscribes the **MulticastSocket** to a multicast group.

n) The **`URL`** constructor determines whether the **`String`** passed as an argument represents a valid Uniform Resource Identifier. If so, the **`URL`** object is initialized to contain the URI; otherwise, an exception of type _____ occurs.

17.2 State whether each of the following is *true or false. If* false, explain why.

a) An application that uses multicast broadcasts **`DatagramPacket`**s to every host on the Internet.
b) UDP is a connection-oriented protocol.
c) With stream sockets a process establishes a connection to another process.
d) A server waits at a port for connections from a client.
e) Datagram packet transmission over a network is reliable—packets are guaranteed to arrive in sequence.
f) For security reasons, many Web browsers such as Netscape *Communicator* allow Java applets to do file processing only on the machines on which they execute.
g) Web browsers often restrict an applet so that it can only communicate with the machine from which it was originally downloaded.
h) IP addresses in the range from **`224.0.0.0`** to **`239.255.255.255`** are reserved for multicast.

ANSWERS TO SELF-REVIEW EXERCISES

17.1 a) **`IOException`**. b) **`UnknownHostException`**. c) **`SocketException`**. d) **`java.net`**. e) **`DatagramSocket`**. f) **`InetAddress`**. g) stream, datagram. h) Uniform Resource Locator. i) Universal Resource Identifier. j) **`http`**. k) **`showDocument`**. l) **`InetAddress`**. m) **`joinGroup`**. n) **`MalformedURLException`**.

17.2 a) False; multicast sends **`DatagramPacket`**s only to hosts that have joined the multicast group. b) False; UDP is a connectionless protocol and TCP is a connection-oriented protocol. c) True. d) True. e) False; packets could be lost and packets can arrive out of order. f) False; most browsers prevent applets from doing file processing on the client machine. g) True. h) True.

EXERCISES

17.3 Distinguish between connection-oriented and connectionless network services.

17.4 How does a client determine the host name of the client computer?

17.5 Under what circumstances would a **`SocketException`** be thrown?

17.6 How can a client get a line of text from a server?

17.7 Describe how a client connects to a server.

17.8 Describe how a server sends data to a client.

17.9 Describe how to prepare a server to receive a stream-based connection request from a single client.

17.10 Describe how to prepare a server to receive connection requests from multiple clients if each client that connects should be processed in parallel with all other connected clients.

17.11 How does a server listen for connections at a port?

17.12 What determines how many connect requests from clients can wait in a queue to connect to a server?

17.13 As described in the text, what reasons might cause a server to refuse a connection request from a client?

17.14 Use a socket connection to allow a client to specify a file name and have the server send the contents of the file or indicate that the file does not exist.

17.15 Modify Exercise 17.14 to allow the client to modify the contents of the file and send the file back to the server for storage. The user can edit the file in a **`JTextArea`**, then click a *save changes* button to send the file back to the server.

17.16 Modify program of Fig. 17.2 to allow users to add their own sites to the list and remove sites from the list.

17.17 Multithreaded servers are quite popular today, especially because of the increasing use of multiprocessing servers. Modify the simple server application presented in Section 17.6 to be a multithreaded server. Then use several client applications and have each of them connect to the server simultaneously. Use a **`Vector`** to store the client threads. **`Vector`** provides several methods of use in this exercise. Method **`size`** determines the number of elements in a **`Vector`**. Method **`elementAt`** returns the element in the specified location (as an **`Object`** reference). Method **`add`** places a new element at the end of the **`Vector`**. Method **`remove`** deletes its argument from the **`Vector`**. Method **`lastElement`** returns an **`Object`** reference to the last object you inserted in the **`Vector`**.

17.18 In the text, we presented a tic-tac-toe program controlled by a multithreaded server. Develop a checkers program modeled after the tic-tac-toe program. The two users should alternate making moves. Your program should mediate the players' moves, determining whose turn it is and allowing only valid moves. The players themselves will determine when the game is over.

17.19 Develop a chess-playing program modeled after the checkers program in the Exercise 17.18.

17.20 Develop a Blackjack card game program in which the server application deals cards to each of the client applets. The server should deal additional cards (as per the rules of the game) to each player as requested.

17.21 Develop a Poker card game in which the server application deals cards to each of the client applets. The server should deal additional cards (as per the rules of the game) to each player as requested.

17.22 *(Modifications to the Multithreaded Tic-Tac-Toe Program)* The programs of Fig. 17.8 and Fig. 17.9 implemented a multithreaded, client/server version of the game Tic-Tac-Toe. Our goal in developing this game was to demonstrate a multithreaded server that could process multiple connections from clients at the same time. The server in the example is really a mediator between the two client applets—it makes sure that each move is valid and that each client moves in the proper order. The server does not determine who won or lost or if there was a draw. Also, there is no capability to allow a new game to be played or to terminate an existing game.

The following is a list of suggested modifications to the multithreaded Tic-Tac-Toe application and applet.

a) Modify the **`TicTacToeServer`** class to test for a win, loss or draw on each move in the game. Send a message to each client applet that indicates the result of the game when the game is over.

b) Modify the **`TicTacToeClient`** class to display a button that when clicked allows the client to play another game. The button should be enabled only when a game completes. Note that both class **`TicTacToeClient`** and class **`TicTacToeServer`** must be modified to reset the board and all state information. Also, the other **`TicTacToeClient`** should be notified that a new game is about to begin so its board and state can be reset.

c) Modify the **`TicTacToeClient`** class to provide a button that allows a client to terminate the program at any time. When the user clicks the button, the server and the other client should be notified. The server should then wait for a connection from another client so a new game can begin.

d) Modify the **`TicTacToeClient`** class and the **`TicTacToeServer`** class so the winner of a game can choose game piece X or O for the next game. Remember: X always goes first.

e) If you would like to be ambitious, allow a client to play against the server while the server waits for a connection from another client.

17.23 *(3-D Multithreaded Tic-Tac-Toe)* Modify the multithreaded, client/server Tic-Tac-Toe program to implement a three-dimensional 4-by-4-by-4 version of the game. Implement the server application to mediate between the two clients. Display the three-dimensional board as four boards containing four rows and four columns each. If you would like to be ambitious, try the following modifications:

a) Draw the board in a three-dimensional manner.
b) Allow the server to test for a win, loss or draw. Beware! There are many possible ways to win on a 4-by-4-by-4 board!

17.24 *(Networked Morse Code)* Modify your solution to Exercise 10.27 to enable two applets to send Morse Code messages to each other through a multithreaded server application. Each applet should allow the user to type normal characters in **`JTextArea`**s, translate the characters into Morse Code and send the coded message through the server to the other client. When messages are received, they should be decoded and displayed as normal characters and as Morse Code. The applet should have two **`JTextArea`**s: one for displaying the other client's messages and one for typing.

18

Multimedia: Images, Animation, Audio and Video

Objectives

- To understand how to get and display images.
- To create animations from sequences of images.
- To customize an animation applet with applet parameters specified in the applet's HTML document.
- To create image maps.
- To be able to get, play, loop and stop sounds using an **`AudioClip`**.

The wheel that squeaks the loudest … gets the grease.
John Billings (Henry Wheeler Shaw)

We'll use a signal I have tried and found far-reaching and easy to yell. Waa-hoo!
Zane Grey

There is a natural hootchy-kootchy motion to a goldfish.
Walt Disney

Between the motion and the act falls the shadow.
Thomas Stearns Eliot, *The Hollow Men*

Outline

18.1 Introduction
18.2 Loading, Displaying and Scaling Images
18.3 Animating a Series of Images
18.4 Customizing `LogoAnimator` via Applet Parameters
18.5 Image Maps
18.6 Loading and Playing Audio Clips
18.7 Internet and World Wide Web Resources

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

18.1 Introduction

Welcome to what may be the largest revolution in the history of the computer industry. Those of us who entered the field decades ago were interested in using computers primarily to perform arithmetic calculations at high speed. As the computer field evolves, we are beginning to realize that the data-manipulation capabilities of computers are now equally important. The "sizzle" of Java is *multimedia*, the use of *sound*, *images*, *graphics* and *video* to make applications "come alive." Today, many people consider two-dimensional color video to be the "ultimate" in multimedia. Within the decade, we expect all kinds of exciting new three-dimensional applications. Java programmers already can use the *Java3D API* to create substantial 3D graphics applications. We discuss the Java3D API in our book *Advanced Java 2 Platform How to Program*.

Multimedia programming offers many new challenges. The field is already enormous and will grow rapidly. People are rushing to equip their computers for multimedia. Most new computers sold today are "multimedia ready," with CD or DVD drives, audio boards and sometimes with special video capabilities.

Among users who want graphics, two-dimensional graphics no longer suffice. Many people now want three-dimensional, high-resolution, color graphics. True three-dimensional imaging may become available within the next decade. Imagine having ultra-high-resolution, "theater-in-the-round," three-dimensional television. Sporting and entertainment events will seem to take place on your living room floor! Medical students worldwide will see operations being performed thousands of miles away, as if they were occurring in the same room. People will be able to learn how to drive with extremely realistic driving simulators in their homes before they get behind the wheel. The possibilities are exciting and endless.

Multimedia demands extraordinary computing power. Until recently, affordable computers with this kind of power were not available. Today's ultrafast processors, like the SPARC Ultra from Sun Microsystems, the Pentium and Itanium from Intel, the Alpha from Compaq Computer Corporation and the processors from MIPS/Silicon Graphics (among others) make effective multimedia possible. The computer and communications industries will be primary beneficiaries of the multimedia revolution. Users will be willing to pay for the faster processors, larger memories and wider communications bandwidths that support demanding multimedia applications. Ironically, users may not have to pay more as fierce competition in these industries drives prices down.

We need programming languages that make creating multimedia applications easy. Most programming languages do not have built-in multimedia capabilities. However, Java provides extensive multimedia facilities that enable you to start developing powerful multimedia applications immediately.

This chapter presents a series of "live-code" examples that cover several interesting multimedia features you will need to build useful applications, including:

1. the basics of manipulating images
2. creating smooth animations
3. customizing an animation applet via parameters supplied from the HTML file that invokes an applet
4. playing audio files with the **`AudioClip`** interface
5. creating image maps that can sense when the cursor is over them even without a mouse click

We will continue our coverage of Java's multimedia capabilities in Chapter 22, where we discuss the *Java Media Framework* (*JMF*) and the *Java Sound APIs*. JMF and Java Sound enable Java programs to play and record audio and video. The JMF even enables Java programs to send audio and video streams—so-called *streaming media*—across a network or the Internet. The chapter exercises for this chapter and Chapter 22 suggest dozens of challenging and interesting projects and even mention some "million-dollar" ideas that could help you make your fortune! When we were creating these exercises, it seemed that the ideas just kept flowing. Multimedia seems to leverage creativity in ways that we have not experienced with "conventional" computer capabilities.

18.2 Loading, Displaying and Scaling Images

Java's multimedia capabilities include graphics, images, animations, sounds and video. We begin our multimedia discussion with images.

The applet of Fig. 18.1 demonstrates loading an ***`Image`*** (package **`java.awt`**) and loading an ***`ImageIcon`*** (package **`javax.swing`**). The applet displays the **`Image`** in its original size and scaled to a larger size, using two versions of **`Graphics`** method ***`drawImage`***. The applet also draws the **`ImageIcon`** using its method ***`paintIcon`***. Class **`ImageIcon`** is easier than **`Image`** to use, because its constructor can receive arguments of several different formats, including a **`byte`** array containing the bytes of an image, an **`Image`** already loaded in memory, a **`String`** representing the location of an image and a **`URL`** representing the location of an image.

```
1  // Fig. 18.1: LoadImageAndScale.java
2  // Load an image and display it in its original size
3  // and scale it to twice its original width and height.
4  // Load and display the same image as an ImageIcon.
5
6  // Java core packages
7  import java.applet.Applet;
8  import java.awt.*;
```

Fig. 18.1 Loading and displaying an image in an applet (part 1 of 2).

```
 9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class LoadImageAndScale extends JApplet {
14    private Image logo1;
15    private ImageIcon logo2;
16
17    // load image when applet is loaded
18    public void init()
19    {
20       logo1 = getImage( getDocumentBase(), "logo.gif" );
21       logo2 = new ImageIcon( "logo.gif" );
22    }
23
24    // display image
25    public void paint( Graphics g )
26    {
27       // draw original image
28       g.drawImage( logo1, 0, 0, this );
29
30       // draw image scaled to fit width of applet
31       // and height of applet minus 120 pixels
32       g.drawImage( logo1, 0, 120,
33          getWidth(), getHeight() - 120, this );
34
35       // draw icon using its paintIcon method
36       logo2.paintIcon( this, g, 180, 0 );
37    }
38
39 } // end class LoadImageAndScale
```

Fig. 18.1 Loading and displaying an image in an applet (part 2 of 2).

Lines 14 and 15 declare an **`Image`** reference and an **`ImageIcon`** reference, respectively. Class **`Image`** is an **`abstract`** class; therefore, the applet cannot create an object of class **`Image`** directly. Rather, the applet must call a method that causes the applet container to load and return the **`Image`** for use in the program. Class **`Applet`** (the superclass of **`JApplet`**) provides a method that does just that. Line 20 in method **`init`** uses **`Applet`** method ***`getImage`*** to load an **`Image`** into the applet. This version of **`getImage`** takes two arguments—the location of the image file and the file name of the image. In the first argument, **`Applet`** method **`getDocumentBase`** returns a **`URL`** representing the location of the image on the Internet (or on your computer if the applet was loaded from your computer). The program assumes that the image is stored in the same directory as the HTML file that invoked the applet. Method **`getDocumentBase`** returns the location of the HTML file on the Internet as an object of class **`URL`**. The second argument specifies an image file name. Java supports several image formats, including *Graphics Interchange Format (GIF)*, *Joint Photographic Experts Group (JPEG)* and *Portable Network Graphics (PNG)*. File names for each of these types end with **`.gif`**, **`.jpg`** (or **`.jpeg`**) and **`.png`**, respectively.

Portability Tip 18.1

*Class **`Image`** is an **`abstract`** class and, as a result, programs cannot instantiate **`Image`** objects. To achieve platform independence, the Java implementation on each platform provides its own subclass of **`Image`** to store image information.*

When line 20 invokes method **`getImage`** to set up loading of the image from the local computer (or downloading of the image from the Internet). When the image is required by the program, the image is loaded in a separate thread of execution. This enables the program to continue execution while the image loads. [*Note:* If the requested file is not available, method **`getImage`** does not indicate an error.]

Class **`ImageIcon`** is not an **`abstract`** class; therefore, a program can create an **`ImageIcon`** object. Line 21 in method **`init`** creates an **`ImageIcon`** object that loads the same **`logo.gif`** image. Class **`ImageIcon`** provides several constructors that enable programs to initialize **`ImageIcon`** objects with images from the local computer or with images stored on the Internet.

The applet's **`paint`** method (lines 25–37) displays the images. Line 28 uses **`Graphics`** method **`drawImage`** to display an **`Image`**. Method **`drawImage`** receives four arguments. The first argument is a reference to the **`Image`** object to display (**`logo1`**). The second and third arguments are the *x*- and *y*-coordinates at which to display the image on the applet; the coordinates indicate the upper-left corner of the image. The last argument is a reference to an ***`ImageObserver`*** object. Normally, the **`ImageObserver`** is the object on which the program displays the image. An **`ImageObserver`** can be any object that implements interface **`ImageObserver`**. Class **`Component`** (one of class **`Applet`**'s indirect superclasses) implements interface **`ImageObserver`**. Therefore, all **`Component`**s (including our applet) are **`ImageObserver`**s. The **`ImageObserver`** argument is important when displaying large images that require a long time to download from the Internet. It is possible that a program will execute the code that displays the image before the image downloads completely. The **`ImageObserver`** is notified to update the displayed image as the remainder of the image loads. When executing this applet, watch carefully as pieces of the image display while the image loads. [*Note*: On faster computers, you might not notice this effect.]

Lines 32–33 use another version of **`Graphics`** method **`drawImage`** to output a *scaled* version of the image. The fourth and fifth arguments specify the *width* and *height* of

the image for display purposes. Method **drawImage** scales the image to fit the specified width and height. In this example, the fourth argument indicates that the width of the scaled image should be the width of the applet, and the fifth argument indicates that the height should be 120 pixels less than the height of the applet. Line 33 determines the width and height of the applet by calling methods **getWidth** and **getHeight** (inherited from class **Component**).

Line 36 uses **ImageIcon** method ***paintIcon*** to display the image. The method requires four arguments—a reference to the **Component** on which to display the image, a reference to the **Graphics** object that will render the image, the *x*-coordinate of the upper-left corner of the image and the *y*-coordinate of the upper-left corner of the image.

If you compare the two techniques for loading and displaying images in this example, you can see that using **ImageIcon** is simpler. You can create objects of class **ImageIcon** directly, and there is no need to use an **ImageObserver** reference when displaying the image. For this reason, we use class **ImageIcon** for the remainder of the chapter. [*Note*: Class **ImageIcon**'s **paintIcon** method does not allow scaling of an image. However, the class provides method **getImage**, which returns an **Image** reference that **Graphics** method **drawImage** can use to display a scaled image.]

18.3 Animating a Series of Images

The next example demonstrates animating a series of images that are stored in an array. The application uses the same techniques to load and display **ImageIcon**s as shown in Fig. 18.1. The animation presented in Fig. 18.2 is designed as a subclass of **JPanel** (called **LogoAnimator**) that can be attached to an application window or possibly to a **JApplet**. Class **LogoAnimator** also defines a **main** method (defined at lines 96–117) to execute the animation as an application. Method **main** defines an instance of class **JFrame** and attaches a **LogoAnimator** object to the **JFrame** to display the animation.

```
1  // Fig. 18.2: LogoAnimator.java
2  // Animation a series of images
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class LogoAnimator extends JPanel
12    implements ActionListener {
13
14    protected ImageIcon images[];        // array of images
15
16    protected int totalImages = 30,      // number of images
17                  currentImage = 0,      // current image index
18                  animationDelay = 50,   // millisecond delay
19                  width,                 // image width
20                  height;                // image height
```

Fig. 18.2 Animating a series of images (part 1 of 3).

```
21
22    protected String imageName = "deitel";  // base image name
23    protected Timer animationTimer;  // Timer drives animation
24
25    // initialize LogoAnimator by loading images
26    public LogoAnimator()
27    {
28       initializeAnimation();
29    }
30
31    // initialize animation
32    protected void initializeAnimation()
33    {
34       images = new ImageIcon[ totalImages ];
35
36       // load images
37       for ( int count = 0; count < images.length; ++count )
38          images[ count ] = new ImageIcon( getClass().getResource(
39             "images/" + imageName + count + ".gif" ) );
40
41       width = images[ 0 ].getIconWidth();   // get icon width
42       height = images[ 0 ].getIconHeight(); // get icon height
43    }
44
45    // display current image
46    public void paintComponent( Graphics g )
47    {
48       super.paintComponent( g );
49
50       images[ currentImage ].paintIcon( this, g, 0, 0 );
51       currentImage = ( currentImage + 1 ) % totalImages;
52    }
53
54    // respond to Timer's event
55    public void actionPerformed( ActionEvent actionEvent )
56    {
57       repaint();  // repaint animator
58    }
59
60    // start or restart animation
61    public void startAnimation()
62    {
63       if ( animationTimer == null ) {
64          currentImage = 0;
65          animationTimer = new Timer( animationDelay, this );
66          animationTimer.start();
67       }
68       else  // continue from last image displayed
69          if ( ! animationTimer.isRunning() )
70             animationTimer.restart();
71    }
72
```

Fig. 18.2 Animating a series of images (part 2 of 3).

```
73      // stop animation timer
74      public void stopAnimation()
75      {
76         animationTimer.stop();
77      }
78
79      // return minimum size of animation
80      public Dimension getMinimumSize()
81      {
82         return getPreferredSize();
83      }
84
85      // return preferred size of animation
86      public Dimension getPreferredSize()
87      {
88         return new Dimension( width, height );
89      }
90
91      // execute animation in a JFrame
92      public static void main( String args[] )
93      {
94         // create LogoAnimator
95         LogoAnimator animation = new LogoAnimator();
96
97         // set up window
98         JFrame window = new JFrame( "Animator test" );
99
100        Container container = window.getContentPane();
101        container.add( animation );
102
103        window.setDefaultCloseOperation( JFrame.EXIT_ON_CLOSE );
104
105        // size and display window
106        window.pack();
107        Insets insets = window.getInsets();
108
109        window.setSize( animation.getPreferredSize().width +
110           insets.left + insets.right,
111           animation.getPreferredSize().height +
112           insets.top + insets.bottom );
113
114        window.setVisible( true );
115        animation.startAnimation();  // begin animation
116
117     }  // end method main
118
119  }  // end class LogoAnimator
```

Fig. 18.2 Animating a series of images (part 3 of 3).

Class **LogoAnimator** maintains an array of **ImageIcon**s that are loaded in method **initializeAnimation** (lines 32–43), which is called from the constructor. As the **for** structure (lines 37–39) creates each **ImageIcon** object, the **ImageIcon** constructor loads one of the animation's 30 images. The constructor argument uses **String** concatenation to assemble the file name from the pieces **"images/"**, **imageName**, **count** and **".gif"**. Each of the images in the animation is in a file called **deitel#.gif**, where # is a value in the range 0–29 specified by the loop's control variable **count**. Lines 41–42 determine the width and height of the animation from the size of the first image in array **images**.

Performance Tip 18.1

It is more efficient to load the frames of the animation as one image than to load each image separately. (A painting program can be used to combine the frames of the animation into one image. If the images are being loaded from the Web, every image loaded requires a separate connection to the site containing the images.

Performance Tip 18.2

Loading all the frames of an animation as one large image can force your program to wait to begin displaying the animation.

After the **LogoAnimator** constructor loads the images, method **main** sets up the window in which the animation will appear and calls **startAnimation** (defined at lines 61–71) to begin the animation. The animation is driven by an instance of class ***Timer*** (package **javax.swing**). A **Timer** generates **ActionEvent**s at a fixed interval in milliseconds (normally specified as an argument to the **Timer**'s constructor) and notifies all of its **ActionListener**s that the event occurred. Lines 63–67 determine whether the **Timer** reference **animationTimer** is **null**. If so, line 64 sets **currentImage** to 0, to indicate that the animation should begin with the image in the first element of array **images**. Line 65 assigns a new **Timer** object to **animationTimer**. The **Timer** constructor receives two arguments—the delay in milliseconds (**animationDelay** is 50 in this example) and the **ActionListener** that will respond to the **Timer**'s **ActionEvent**s. Class **LogoAnimator** implements **ActionListener** so line 65 specifies **this** as the listener. Line 66 starts the **Timer** object. Once started, **animationTimer** will generate an **ActionEvent** every 50 milliseconds. Lines 69–70 enable a program to restart an animation that the program stopped previously. For example, to make an animation "browser friendly" in an applet, the animation should stop when the user switches Web pages. If the user returns to the Web page with the animation, method **startAnimation** can be called to restart the animation. The **if** condition at line 73 uses **Timer** method **isRunning** to determine whether the **Timer** is running (i.e., generating events). If it is not running, line 70 calls **Timer** method **restart** to indicate that the **Timer** should start generating events again.

In response to every **Timer** event in this example, the program calls method **actionPerformed** (lines 55–58). Line 57 calls **LogoAnimator**'s **repaint** method to schedule a call to the **LogoAnimator**'s **update** method (inherited from class **JPanel**) which, in turn, calls **LogoAnimator**'s **paintComponent** method (lines 46–52). Remember that any subclass of **JComponent** that performs drawing should do so in its **paintComponent** method. As mentioned in Chapter 13, the first statement in any **paintComponent** method should be a call to the superclass's **paintComponent** method to ensure that Swing components are displayed correctly.

Lines 50–51 paint the **ImageIcon** at element **currentImage** in the array and prepare for the next image to be displayed by incrementing **currentImage** by 1. Notice the modulus calculation to ensure that the value of **currentImage** is set to 0 when it is incremented past 29 (the last element subscript in the array).

Method **stopAnimation** (lines 74–77) stops the animation with line 76, which calls **Timer** method ***stop*** to indicate that the **Timer** should stop generating events. This prevents **actionPerformed** from calling **repaint** to initiate the painting of the next image in the array.

Software Engineering Observation 18.1

When creating an animation for use in an applet, provide a mechanism for disabling the animation when the user browses a new Web page separate from the page on which the animation applet resides.

Methods **getMinimumSize** (lines 80–83) and **getPreferredSize** (lines 86–89) override the corresponding methods inherited from class **Component** and enable layout managers to determine the appropriate size of a **LogoAnimator** in a layout. In this example, the images are 160 pixels wide and 80 pixels tall, so method **getPreferredSize** returns a **Dimension** object containing the numbers 160 and 80. Method **getMinimumSize** simply calls **getPreferredSize** (a common programming practice).

Lines 107–112 of **main** size the application window based on the **LogoAnimator**'s preferred size and the window's *insets*. The insets specify the number of pixels for the window's top, bottom, left and right borders. Using the insets of the window ensures that the window's *client area* is large enough to display the **LogoAnimator** correctly. The client area is the part of a window in which the window displays GUI components. The program obtains the window's insets by calling method ***getInsets*** at line 107. The method returns an ***Insets*** object that contains **public** data members ***top***, ***bottom***, ***left*** and ***right***.

18.4 Customizing LogoAnimator via Applet Parameters

When browsing the World Wide Web, you often will come across applets that are in the public domain—you can use them free of charge on your own Web pages (normally in exchange for crediting the applet's creator). One common feature of such applets is the ability to be customized via parameters that are supplied from the HTML file that invokes the applet. For example, the HTML

```
<html>
<applet code = "LogoApplet.class" width = 400 height = 400>
<param name = "totalimages" value = "30">
<param name = "imagename" value = "deitel">
<param name = "animationdelay" value = "200">
</applet>
</html>
```

from file **LogoApplet.html**, invokes the applet **LogoApplet** (Fig. 18.4) and specifies three parameters. The ***param*** *tag* lines must appear between the starting and ending **applet** tags. Each parameter has a ***name*** and a ***value***. **Applet** method ***getParameter*** returns a **String** representing the **value** associated with a specific parameter **name**. The argument to **getParameter** is a **String** containing the name of the parameter in the **param** tag. For example, the statement

```
parameter = getParameter( "animationdelay" );
```

gets the value 200 associated with parameter **animationdelay** and assigns it to **String** reference **parameter**. If there is not a **param** tag containing the specified parameter name, **getParameter** returns **null**.

Class **LogoAnimator2** (Fig. 18.3) extends class **LogoAnimator** and adds a constructor that takes three arguments—the total number of images in the animation, the delay between displaying images and the base image name. Class **LogoApplet** (Fig. 18.4) allows Web page designers to customize the animation to use their own images. Three parameters are provided in the applet's HTML document. Parameter **animationdelay** is the number of milliseconds to sleep between displaying images. This value will be converted to an integer and used as the value for instance variable **sleepTime**. Parameter **imagename** is the base name of the images to be loaded. This **String** will be assigned to instance variable **imageName**. The applet assumes that the images are in a subdirectory named **images** that can be found in the same directory as the applet. The applet also assumes that the image file names are numbered from 0 (as in Fig. 18.2). Parameter **totalimages** represents the total number of images in the animation. Its value will be converted to an integer and assigned to instance variable **totalImages**.

```
1  // Fig. 18.3: LogoAnimator2.java
2  // Animating a series of images
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
10 public class LogoAnimator2 extends LogoAnimator {
11
12    // default constructor
13    public LogoAnimator2()
14    {
15       super();
16    }
17
18    // new constructor to support customization
19    public LogoAnimator2( int count, int delay, String name )
20    {
21       totalImages = count;
22       animationDelay = delay;
23       imageName = name;
24
25       initializeAnimation();
26    }
27
```

Fig. 18.3 **LogoAnimator2** subclass of **LogoAnimator** (Fig. 18.2) adds a constructor for customizing the number of images, animation delay and base image name (part 1 of 2).

```
28     // start animation as application in its own window
29     public static void main( String args[] )
30     {
31        // create LogoAnimator
32        LogoAnimator2 animation = new LogoAnimator2();
33
34        // set up window
35        JFrame window = new JFrame( "Animator test" );
36
37        Container container = window.getContentPane();
38        container.add( animation );
39
40        window.setDefaultCloseOperation( JFrame.EXIT_ON_CLOSE );
41
42        // size and display window
43        window.pack();
44        Insets insets = window.getInsets();
45
46        window.setSize( animation.getPreferredSize().width +
47           insets.left + insets.right,
48           animation.getPreferredSize().height +
49           insets.top + insets.bottom );
50
51        window.setVisible( true );
52        animation.startAnimation();  // begin animation
53
54     }  // end method main
55
56  }  // end class LogoAnimator2
```

Fig. 18.3 **LogoAnimator2** subclass of **LogoAnimator** (Fig. 18.2) adds a constructor for customizing the number of images, animation delay and base image name (part 2 of 2).

```
1  // Fig. 18.4: LogoApplet.java
2  // Customizing an applet via HTML parameters.
3  //
4  // HTML parameter "animationdelay" is an int indicating
5  // milliseconds to sleep between images (default 50).
6  //
7  // HTML parameter "imagename" is the base name of the images
8  // that will be displayed (i.e., "deitel" is the base name
9  // for images "deitel0.gif," "deitel1.gif," etc.). The applet
10 // assumes that images are in an "images" subdirectory of
11 // the directory in which the applet resides.
12 //
13 // HTML parameter "totalimages" is an integer representing the
14 // total number of images in the animation. The applet assumes
15 // images are numbered from 0 to totalimages - 1 (default 30).
16
17 // Java core packages
18 import java.awt.*;
```

Fig. 18.4 Customizing an animation applet via the **param** HTML tag (part 1 of 2).

```
19
20 // Java extension packages
21 import javax.swing.*;
22
23 public class LogoApplet extends JApplet {
24
25    // obtain parameters from HTML and customize applet
26    public void init()
27    {
28       String parameter;
29
30       // get animation delay from HTML document
31       parameter = getParameter( "animationdelay" );
32
33       int animationDelay = ( parameter == null ?
34          50 : Integer.parseInt( parameter ) );
35
36       // get base image name from HTML document
37       String imageName = getParameter( "imagename" );
38
39       // get total number of images from HTML document
40       parameter = getParameter( "totalimages" );
41
42       int totalImages = ( parameter == null ?
43          0 : Integer.parseInt( parameter ) );
44
45       // create instance of LogoAnimator
46       LogoAnimator2 animator;
47
48       if ( imageName == null || totalImages == 0 )
49          animator = new LogoAnimator2();
50       else
51          animator = new LogoAnimator2( totalImages,
52             animationDelay, imageName );
53
54       // attach animator to applet and start animation
55       getContentPane().add( animator );
56       animator.startAnimation();
57
58    }  // end method init
59
60 }  // end class LogoApplet
```

Fig. 18.4 Customizing an animation applet via the **param** HTML tag (part 2 of 2).

Class **LogoApplet** (Fig. 18.4) defines an **init** method in which the three HTML parameters are read with **Applet** method **getParameter** (lines 31, 37 and 40). After the applet reads these parameters and the two integer parameters are converted to **int** values, the **if/else** structure at lines 48 through 51 creates a **LogoAnimator2** and calls its three-argument constructor. If the **imageName** is **null** or **totalImages** is **0**, the applet calls the default **LogoAnimator2** constructor and uses the default animation. Otherwise, the applet passes **totalImages**, **animationDelay** and **imageName** to the three-argument **LogoAnimator2** constructor, and the constructor uses those arguments to customize the animation. **LogoAnimator2**'s three-argument constructor invokes **LogoAnimator**'s **initalizeAnimation** method to load the images and determine the width and height of the animation.

18.5 Image Maps

Image maps are a common technique used to create interactive Web pages. An image map is an image that has *hot areas* that the user can click to accomplish a task, such as loading a different Web page into a browser. When the user positions the mouse pointer over a hot area, normally a descriptive message appears in the status area of the browser or in a pop-up window.

Figure 18.5 loads an image containing several of the common tip icons used throughout this book. The program allows the user to position the mouse pointer over an icon and display a descriptive message for the icon. Event handler **mouseMoved** (lines 42–46) takes the mouse coordinates and passes them to method **translateLocation** (lines 63–76). Method **translateLocation** tests the coordinates to determine the icon over which the mouse was positioned when the **mouseMoved** event occurred. Method **translateLocation** then returns a message indicating what the icon represents. This message is displayed in the **appletviewer**'s (or browser's) status bar.

```
1  // Fig. 18.5: ImageMap.java
2  // Demonstrating an image map.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class ImageMap extends JApplet {
12    private ImageIcon mapImage;
13
14    private String captions[] = { "Common Programming Error",
15       "Good Programming Practice",
16       "Graphical User Interface Tip", "Performance Tip",
17       "Portability Tip", "Software Engineering Observation",
18       "Testing and Debugging Tip" };
19
```

Fig. 18.5 Demonstrating an image map (part 1 of 4).

```
20     // set up mouse listeners
21     public void init()
22     {
23        addMouseListener(
24
25           new MouseAdapter() {
26
27              // indicate when mouse pointer exits applet area
28              public void mouseExited( MouseEvent event )
29              {
30                 showStatus( "Pointer outside applet" );
31              }
32
33           }  // end anonymous inner class
34
35        ); // end addMouseListener method call
36
37        addMouseMotionListener(
38
39           new MouseMotionAdapter() {
40
41              // determine icon over which mouse appears
42              public void mouseMoved( MouseEvent event )
43              {
44                 showStatus( translateLocation(
45                    event.getX(), event.getY() ) );
46              }
47
48           }  // end anonymous inner class
49
50        ); // end addMouseMotionListener method call
51
52        mapImage = new ImageIcon( "icons.png" );
53
54     }  // end method init
55
56     // display mapImage
57     public void paint( Graphics g )
58     {
59        mapImage.paintIcon( this, g, 0, 0 );
60     }
61
62     // return tip caption based on mouse coordinates
63     public String translateLocation( int x, int y )
64     {
65        // if coordinates outside image, return immediately
66        if ( x >= mapImage.getIconWidth() ||
67             y >= mapImage.getIconHeight() )
68           return "";
69
70        // determine icon number (0 - 6)
71        int iconWidth = mapImage.getIconWidth() / 7;
72        int iconNumber = x / iconWidth;
```

Fig. 18.5 Demonstrating an image map (part 2 of 4).

```
73
74          // return appropriate icon caption
75          return captions[ iconNumber ];
76       }
77
78    }  // end class ImageMap
```

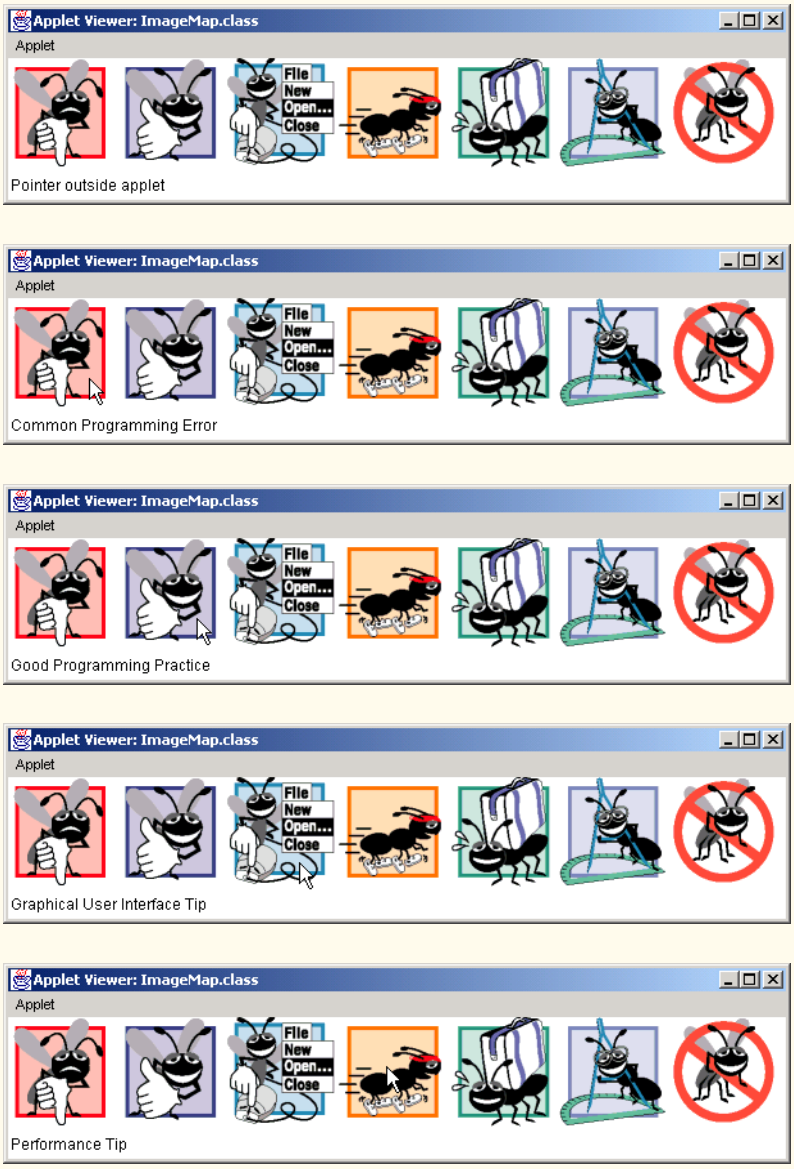


Fig. 18.5 Demonstrating an image map (part 3 of 4).

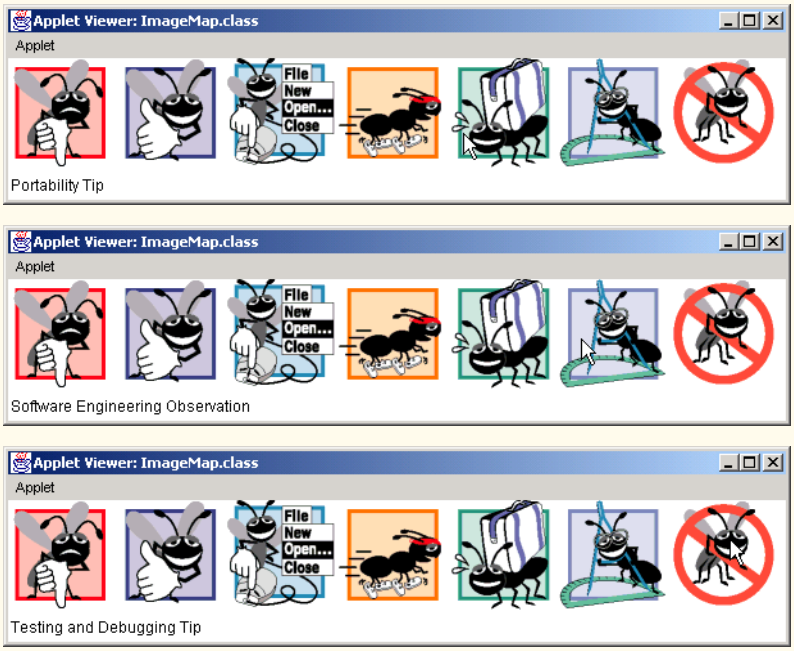


Fig. 18.5 Demonstrating an image map (part 4 of 4).

Clicking in this applet will not cause any action. In Chapter 17, Networking, we discussed the techniques required to load another Web page into a browser via **URL**s and the **AppletContext** interface. Using those techniques, this applet could associate each icon with a **URL** that the browser would display when the user clicks the icon.

18.6 Loading and Playing Audio Clips

Java programs can manipulate and play *audio clips*. It is easy for users to capture their own audio clips, and there are many clips available in software products and over the Internet. Your system needs to be equipped with audio hardware (speakers and a sound board) to be able to play the audio clips.

Java provides several mechanisms for playing sounds in an applet. The two simplest methods are the **Applet**'s ***play*** method and the ***play*** method from the ***AudioClip*** interface. Additional audio capabilities are discussed in Chapter 22. If you would like to play a sound once in a program, the **Applet** method **play** loads the sound and plays it once; the sound is marked for garbage collection after it plays. The **Applet** method **play** has two forms:

```
public void play( URL location, String soundFileName );
public void play( URL soundURL );
```

The first version loads the audio clip stored in file **soundFileName** from **location** and plays the sound. The first argument is normally a call to the applet's **getDocument-**

Base or ***getCodeBase*** method. Method **getDocumentBase** indicates the location of the HTML file that loaded the applet (if the applet is in a package, this indicates the location of the package or JAR file containing the package). Method **getCodeBase** indicates the location of the applet's **.class** file. The second version of method **play** takes a **URL** that contains the location and the file name of the audio clip. The statement

```
play( getDocumentBase(), "hi.au" );
```

loads the audio clip in file **hi.au** and plays it once.

The *sound engine* that plays the audio clips supports several audio file formats, including *Sun Audio file format* (***.au*** *extension*), *Windows Wave file format* (***.wav*** *extension*), *Macintosh AIFF file format* (***.aif*** *or* ***.aiff*** *extension*) and *Musical Instrument Digital Interface* (*MIDI*) *file format* (***.mid*** *or* ***.rmi*** *extensions*). The Java Media Framework (JMF) and Java Sound APIs support additional formats.

The program of Fig. 18.6 demonstrates loading and playing an ***AudioClip*** (package **java.applet**). This technique is more flexible than **Applet** method **play**. An applet can use an AudioClip to store audio for repeated use throughout the program's execution. **Applet** method ***getAudioClip*** has two forms that take the same arguments as method **play** described previously. Method **getAudioClip** returns a reference to an **AudioClip**. An **AudioClip** has three methods—***play***, ***loop*** and ***stop***. Method **play** plays the audio once. Method **loop** continuously loops the audio clip in the background. Method **stop** terminates an audio clip that is currently playing. In the program, each of these methods is associated with a button on the applet.

Lines 62–63 in the applet's **init** method use **getAudioClip** to load two audio files—a Windows Wave file (**welcome.wav**) and a Sun Audio file (**hi.au**). The user can select which audio clip to play from **JComboBox chooseSound**. Notice that the applet's **stop** method is overridden at lines 69–72. When the user switches Web pages, the applet container calls the applet's **stop** method. This enables the applet to stop playing the audio clip. Otherwise, the audio clip continues to play in the background—even if the applet is not displayed in the browser. This is not really a problem, but it can be annoying to the user if the audio clip is looping. The **stop** method is provided here as a convenience to the user.

Good Programming Practice 18.1

When playing audio clips in an applet or application, provide a mechanism for the user to disable the audio.

```
1  // Fig. 18.6: LoadAudioAndPlay.java
2  // Load an audio clip and play it.
3
4  // Java core packages
5  import java.applet.*;
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
```

Fig. 18.6 Loading and playing an **AudioClip** (part 1 of 3).

```
11
12 public class LoadAudioAndPlay extends JApplet {
13    private AudioClip sound1, sound2, currentSound;
14    private JButton playSound, loopSound, stopSound;
15    private JComboBox chooseSound;
16
17    // load the image when the applet begins executing
18    public void init()
19    {
20       Container container = getContentPane();
21       container.setLayout( new FlowLayout() );
22
23       String choices[] = { "Welcome", "Hi" };
24       chooseSound = new JComboBox( choices );
25
26       chooseSound.addItemListener(
27
28          new ItemListener() {
29
30             // stop sound and change to sound to user's selection
31             public void itemStateChanged( ItemEvent e )
32             {
33                currentSound.stop();
34
35                currentSound =
36                   chooseSound.getSelectedIndex() == 0 ?
37                      sound1 : sound2;
38             }
39
40          }  // end anonymous inner class
41
42       ); // end addItemListener method call
43
44       container.add( chooseSound );
45
46       // set up button event handler and buttons
47       ButtonHandler handler = new ButtonHandler();
48
49       playSound = new JButton( "Play" );
50       playSound.addActionListener( handler );
51       container.add( playSound );
52
53       loopSound = new JButton( "Loop" );
54       loopSound.addActionListener( handler );
55       container.add( loopSound );
56
57       stopSound = new JButton( "Stop" );
58       stopSound.addActionListener( handler );
59       container.add( stopSound );
60
61       // load sounds and set currentSound
62       sound1 = getAudioClip( getDocumentBase(), "welcome.wav" );
63       sound2 = getAudioClip( getDocumentBase(), "hi.au" );
```

Fig. 18.6 Loading and playing an **AudioClip** (part 2 of 3).

```
64          currentSound = sound1;
65
66       }  // end method init
67
68       // stop the sound when the user switches Web pages
69       public void stop()
70       {
71          currentSound.stop();
72       }
73
74       // private inner class to handle button events
75       private class ButtonHandler implements ActionListener {
76
77          // process play, loop and stop button events
78          public void actionPerformed( ActionEvent actionEvent )
79          {
80             if ( actionEvent.getSource() == playSound )
81                currentSound.play();
82
83             else if ( actionEvent.getSource() == loopSound )
84                currentSound.loop();
85
86             else if ( actionEvent.getSource() == stopSound )
87                currentSound.stop();
88          }
89       }
90
91    }  // end class LoadAudioAndPlay
```

Fig. 18.6 Loading and playing an **`AudioClip`** (part 3 of 3).

18.7 Internet and World Wide Web Resources

This section presents several Internet and Web resources for multimedia-related sites. (Additional resources are provided in Chapter 22.)

`www.nasa.gov/gallery/index.html`
The *NASA multimedia gallery* contains a wide variety of images, audio clips and video clips that you can download and use to test your Java multimedia programs.

`sunsite.sut.ac.jp/multimed/`
The *Sunsite Japan Multimedia Collection* also provides a wide variety of images, audio clips and video clips that you can download for educational purposes.

`www.anbg.gov.au/anbg/index.html`
The *Australian National Botanic Gardens* Web site provides links to sounds of many animals. Try, for example, the *Common Birds* link.

www.thefreesite.com
TheFreeSite.com has links to free sounds and clip art.

www.soundcentral.com
SoundCentral provides audio clips in WAV, AU, AIFF and MIDI formats.

www.animationfactory.com
The *Animation Factory* provides thousands of free GIF animations for personal use.

www.clipart.com
ClipArt.com contains links to Web sites that provide free art.

www.pngart.com
PNGART.com provides over 50,000 free images in PNG format, in an effort to help this newer image format gain popularity.

developer.java.sun.com/developer/techDocs/hi/repository
The *Java Look-and-Feel Graphics Repository* provides standard images for use in a Swing GUI.

SUMMARY

- **Applet** method **getImage** loads an **Image**. One version of **getImage** takes two arguments—a location where the image is stored, and the file name of the image.
- **Applet** method **getDocumentBase** returns the location of the applet's HTML file on the Internet as an object of class **URL** (package **java.net**).
- Java supports several image formats, including Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPEG) and Portable Network Graphics (PNG). File names for each of these types end with **.gif**, **.jpg** (or **.jpeg**) or **.png**, respectively.
- Class **ImageIcon** provides constructors that allow an **ImageIcon** object to be initialized with an image from the local computer or with an image stored on a Web server on the Internet.
- **Graphics** method **drawImage** receives four arguments—a reference to the **Image** object in which the image is stored, the *x*- and *y*-coordinates where the image should be displayed and a reference to an **ImageObserver** object.
- Another version of **Graphics** method **drawImage** outputs a *scaled* image. The fourth and fifth arguments specify the width and height of the image for display purposes.
- Interface **ImageObserver** is implemented by class **Component** (an indirect superclass of **Applet**). **ImageObserver**s are notified to update an image that was displayed as the remainder of the image is loaded.
- **ImageIcon** method **paintIcon** displays the **ImageIcon**'s image. The method requires four arguments—a reference to the **Component** on which the image will be displayed, a reference to the **Graphics** object used to render the image, the *x*-coordinate of the upper-left corner of the image and the *y*-coordinate of the upper-left corner of the image.
- Class **ImageIcon**'s **paintIcon** method does not allow scaling of an image. The class provides method **getImage**, which returns an **Image** reference that can be used with **Graphics** method **drawImage** to display a scaled version of an image.
- **Timer** objects generate **ActionEvent**s at fixed intervals in milliseconds and notify their registered **ActionListener**s that the events occurred. The **Timer** constructor receives two arguments—the delay in milliseconds and the **ActionListener**. **Timer** method **start** indicates that the **Timer** should start generating events. **Timer** method **stop** indicates that the **Timer** should stop generating events. **Timer** method **restart** indicates that the **Timer** should start generating events again.

- Applets can be customized via parameters (the **<param>** tag) that are supplied from the HTML file that invokes the applet. The **<param>** tag lines must appear between the starting **applet** tag and the ending **applet** tag. Each parameter has a **name** and a **value**.
- **Applet** method **getParameter** gets the **value** associated with a specific parameter and returns the **value** as a **String**. The argument passed to **getParameter** is a **String** containing the name of the parameter in the **param** tag. If there is no **param** tag containing the specified parameter, **getParameter** returns **null**.
- An image map is an image that has hot areas that the user can click to accomplish a task, such as loading a different Web page into a browser.
- **Applet** method **play** has two forms:

```
public void play( URL location, String soundFileName );
public void play( URL soundURL );
```

- One version loads the audio clip stored in file **soundFileName** from **location** and plays the sound; the other takes a **URL** that contains the location and the file name of the audio clip.
- **Applet** method **getDocumentBase** indicates the location of the HTML file that loaded the applet. Method **getCodeBase** indicates where the **.class** file for an applet is located.
- The sound engine that plays audio clips supports several audio file formats, including Sun Audio file format (**.au** extension), Windows Wave file format (**.wav** extension), Macintosh AIFF file format (**.aif** or **.aiff** extension) and Musical Instrument Digital Interface (MIDI) file format (**.mid** or **.rmi** extensions). The Java Media Framework (JMF) supports other additional formats.
- **Applet** method **getAudioClip** has two forms that take the same arguments as the **play** method. Method **getAudioClip** returns a reference to an **AudioClip**. **AudioClip**s have three methods—**play**, **loop** and **stop**. Method **play** plays the audio once. Method **loop** continuously loops the audio clip. Method **stop** terminates an audio clip that is currently playing.

TERMINOLOGY

.aif file name extension
.aiff file name extension
.au file name extension
.gif file name extension
.jpeg file name extension
.jpg file name extension
.mid file name extension
.rmi file name extension
.wav file name extension
animating a series of images
animation
audio clip
customize an applet
drawImage method of **Graphics**
getAudioClip method of **Applet**
getCodeBase method of **Applet**
getDocumentBase method of **Applet**
getHeight method of **Component**
getIconHeight method of **ImageIcon**
getIconWidth method of **ImageIcon**
getImage method of **Applet**
getImage method of **ImageIcon**
getParameter method of **Applet**
getWidth method of **Component**
graphics
Graphics Interchange Format (GIF)
height of an image
hot area of an image map
Image class
image map
ImageIcon class
ImageObserver interface
images
information button
Joint Photographic Experts Group (JPEG)
loop method of interface **AudioClip**
Macintosh AIFF file (**.aif** or **.aiff**)
multimedia
Musical Instrument Digital Interface (MIDI)
mute button
name attribute of **param** tag
paintIcon method of class **ImageIcon**

param tag
play method of class **Applet**
play method of interface **AudioClip**
restart method of class **Timer**
scaling an image
sound
sound engine
space/time trade-off
start method of class **Timer**
stop method of class **Timer**
stop method of interface **AudioClip**
Sun Audio file format (**.au**)
Timer class
update method of class **Component**
value attribute of **param** tag
volume control
width of an image
Windows Wave file (**.wav**)

SELF-REVIEW EXERCISES

18.1 Fill in the blanks in each of the following statements:

a) **Applet** method _____ loads an image into an applet.
b) **Applet** method _____ returns as an object of class **URL** the location on the Internet of the HTML file that invoked the applet.
c) **Graphics** method _____ displays an image on an applet.
d) Java provides two mechanisms for playing sounds in an applet—the **Applet**'s **play** method and the **play** method from the _____ interface.
e) An _____ is an image that has *hot areas* that the user can click to accomplish a task such as loading a different Web page.
f) Method _____ of class **ImageIcon** displays the **ImageIcon**'s image.
g) Java supports several image formats, including _____, _____ and _____.

18.2 State whether each of the following is true or false. If false, explain why.

a) A sound will be garbage collected as soon as it has finished playing.
b) Class **ImageIcon** provides constructors that allow an **ImageIcon** object to be initialized only with an image from the local computer.
c) **Applet** method **getParameter** gets the **value** associated with a specific HTML parameter and returns the **value** as a **String**.

ANSWERS TO SELF-REVIEW EXERCISES

18.1 a) **getImage**. b) **getDocumentBase**. c) **drawImage**. d) **AudioClip**. e) image map. f) **paintIcon**. g) Graphics Interchange Format (GIF), Joint Photographic Experts Group (JPEG) Portable Network Graphics (PNG).

18.2 a) False. The sound will be marked for garbage collection (if it is not referenced by an **AudioClip**) and will be garbage collected when the garbage collector is able to run. b) False. **ImageIcon** can load images from the Internet as well. c) True.

EXERCISES

18.3 Describe how to make an animation "browser friendly."

18.4 Describe the Java methods for playing and manipulating audio clips.

18.5 How can Java applets be customized with information from an HTML file?

18.6 Explain how image maps are used. List 10 examples in which image maps are used.

18.7 *(Randomly Erasing an Image)* Suppose an image is displayed in a rectangular screen area. One way to erase the image is simply to set every pixel to the same color immediately, but this is a dull visual effect. Write a Java program that displays an image and then erases it by using random-

number generation to select individual pixels to erase. After most of the image is erased, erase all of the remaining pixels at once. You can refer to individual pixels by having a line that starts and ends at the same point. You might try several variants of this problem. For example, you might display lines randomly or display shapes randomly to erase regions of the screen.

18.8 *(Text Flasher)* Create a Java program that repeatedly flashes text on the screen. Do this by alternating the text with a plain background-color image. Allow the user to control the "blink speed" and the background color or pattern.

18.9 *(Image Flasher)* Create a Java program that repeatedly flashes an image on the screen. Do this by alternating the image with a plain background-color image.

18.10 *(Digital Clock)* Implement a program that displays a digital clock on the screen. You might add options to scale the clock; display day, month and year; issue an alarm; play certain audios at designated times and the like.

18.11 *(Calling Attention to an Image)* If you want to emphasize an image, you might place a row of simulated light bulbs around your image. You can let the light bulbs flash in unison, or you can let them fire on and off in sequence one after the other.

18.12 *(Image Zooming)* Create a program that enables you to zoom in on, or away from, an image.

SPECIAL SECTION: CHALLENGING MULTIMEDIA PROJECTS

The preceding exercises are keyed to the text and designed to test the reader's understanding of fundamental multimedia concepts. This section includes a collection of advanced multimedia projects. The reader should find these problems challenging, yet entertaining. The problems vary considerably in difficulty. Some require an hour or two of program writing and implementation. Others are useful for lab assignments that might require two or three weeks of study and implementation. Some are challenging term projects. [*Note*: Solutions are not provided for these exercises.].

18.13 *(Animation)* Create a a general purpose Java animation program. Your program should allow the user to specify the sequence of frames to be displayed, the speed at which the images are displayed, audios that should be played while the animation is running and so on.

18.14 *(Limericks)* Modify the limerick-writing program you wrote in Exercise 10.10 to sing the limericks your program creates.

18.15 *(Random Inter-Image Transition)* This provides a nice visual effect. If you are displaying one image in a given area on the screen and you would like to transition to another image in the same screen area, store the new screen image in an off-screen buffer and randomly copy pixels from the new image to the display area, overlaying the previous pixels at those locations. When the vast majority of the pixels have been copied, copy the entire new image to the display area to be sure you are displaying the complete new image. To implement this program, you may need to use the **`PixelGrabber`** and **`MemoryImageSource`** classes (see the Java API documentation for descriptions of these classes). You might try several variants of this problem. For example, try selecting all the pixels in a randomly selected straight line or shape in the new image, and overlay those pixels above the corresponding positions of the old image.

18.16 *(Background Audio)* Add background audio to one of your favorite applications by using the **`loop`** method of class **`AudioClip`** to play the sound in the background while you interact with your application in the normal way.

18.17 *(Scrolling Marquee Sign)* Create a Java program that scrolls dotted characters from right to left (or from left to right if that is appropriate for your language) across a Marquee-like display sign. As an option, display the text in a continuous loop, so that after the text disappears at one end it reappears at the other end.

18.18 *(Scrolling Image Marquee)* Create a Java program that scrolls an image across a Marquee screen.

18.19 *(Analog Clock)* Create a Java program that displays an analog clock with hour, minute and second hands that move appropriately as the time changes.

18.20 *(Dynamic Audio and Graphical Kaleidoscope)* Write a kaleidoscope program that displays reflected graphics to simulate the popular children's toy. Incorporate audio effects that "mirror" your program's dynamically changing graphics.

18.21 *(Automatic Jigsaw Puzzle Generator)* Create a Java jigsaw puzzle generator and manipulator. Your user specifies an image. Your program loads and displays the image. Your program then breaks the image into randomly selected shapes and shuffles the shapes. The user then uses the mouse to move the puzzle pieces around to solve the puzzle. Add appropriate audio sounds as the pieces are being moved around and snapped back into place. You might keep tabs on each piece and where it really belongs and then use audio effects to help the user get the pieces into the correct positions.

18.22 *(Maze Generator and Walker)* Develop a multimedia-based maze generator and traverser program based on the maze programs you wrote in Exercise 7.38–Exercise 7.40. Let the user customize the maze by specifying the number of rows and columns and by indicating the level of difficulty. Have an animated mouse walk the maze. Use audio to dramatize the movement of your mouse character.

18.23 *(One-Armed Bandit)* Develop a multimedia simulation of a one-armed bandit. Have three spinning wheels. Place various fruits and symbols on each wheel. Use true random-number generation to simulate the spinning of each wheel and the stopping of each wheel on a symbol.

18.24 *(Horse Race)* Create a Java simulation of a horse race. Have multiple contenders. Use audios for a race announcer. Play the appropriate audios to indicate the correct status of each of the contenders throughout the race. Use audios to announce the final results. You might try to simulate the kinds of horse-racing games that are often played at carnivals. The players get turns at the mouse and have to perform some skill-oriented manipulation with the mouse to advance their horses.

18.25 *(Shuffleboard)* Develop a multimedia-based simulation of the game of shuffleboard. Use appropriate audio and visual effects.

18.26 *(Game of Pool)* Create a multimedia-based simulation of the game of pool. Each player takes turns using the mouse to position a pool stick and to hit the stick against the ball at the appropriate angle to try to get the pool balls to fall into the pockets. Your program should keep score.

18.27 *(Artist)* Design a Java art program that will give an artist a great variety of capabilities to draw, use images, use animations, etc., to create a dynamic multimedia art display.

18.28 *(Fireworks Designer)* Create a Java program that someone might use to create a fireworks display. Create a variety of fireworks demonstrations. Then orchestrate the firing of the fireworks for maximum effect.

18.29 *(Floor Planner)* Develop a Java program that will help someone arrange furniture in his or her home. Add features that enable the person to achieve the best possible arrangement.

18.30 *(Crossword)* Crossword puzzles are among the most popular pastimes. Develop a multimedia-based crossword-puzzle program. Your program should enable the player to place and erase words easily. Tie your program to a large computerized dictionary. Your program also should be able to suggest words based on which letters have already been filled in. Provide other features that will make the crossword-puzzle enthusiast's job easier.

18.31 *(15 Puzzle)* Write a multimedia-based Java program that enables the user to play the game of 15. There is a 4-by-4 board for a total of 16 slots. One of the slots is empty. The other slots are occupied by 15 tiles numbered 1 through 15. Any tile next to the currently empty slot can be moved into

that slot by clicking on the tile. Your program should create the board with the tiles out of order. The goal is to arrange the tiles into sequential order, row by row.

18.32 *(Reaction Time/Reaction Precision Tester)* Create a Java program that moves a randomly created shape around the screen. The user moves the mouse to catch and click on the shape. The shape's speed and size can be varied. Keep statistics on how much time the user typically takes to catch a shape of a given size. The user will probably have more difficulty catching faster moving, smaller shapes.

18.33 *(Calendar/Tickler File)* Using both audio and images create a general purpose calendar and "tickler" file. For example, the program should sing "Happy Birthday" when you use it on your birthday. Have the program display images and play audios associated with important events. Also, have the program remind you in advance of these important events. It would be nice, for example, to have the program give you a week's notice so you can pick up an appropriate greeting card for that special person.

18.34 *(Rotating Images)* Create a Java program that lets you rotate an image through some number of degrees (out of a maximum of 360 degrees). The program should let you specify that you want to spin the image continuously. The program should let you adjust the spin speed dynamically.

18.35 *(Coloring Black and White Photographs and Images)* Create a Java program that lets you paint a black and white photograph with color. Provide a color palette for selecting colors. Your program should let you apply different colors to different regions of the image.

18.36 *(Multimedia-Based Simpletron Simulator)* Modify the Simpletron simulator that you developed in the exercises in the previous chapters to include multimedia features. Add computer-like sounds to indicate that the Simpletron is executing instructions. Add a breaking glass sound when a fatal error occurs. Use flashing lights to indicate which cells of memory and/or which registers are currently being manipulated. Use other multimedia techniques, as appropriate, to make your Simpletron simulator more valuable to its users as an educational tool.

19

Data Structures

Objectives

- To be able to form linked data structures using references, self-referential classes and recursion.
- To be able to create and manipulate dynamic data structures, such as linked lists, queues, stacks and binary trees.
- To understand various important applications of linked data structures.
- To understand how to create reusable data structures with classes, inheritance and composition.

Much that I bound, I could not free;
Much that I freed returned to me.
Lee Wilson Dodd

'Will you walk a little faster?' said a whiting to a snail,
'There's a porpoise close behind us, and he's treading on my tail.'
Lewis Carroll

There is always room at the top.
Daniel Webster

Push on—keep moving.
Thomas Morton

I think that I shall never see
A poem lovely as a tree.
Joyce Kilmer

Outline

19.1 Introduction
19.2 Self-Referential Classes
19.3 Dynamic Memory Allocation
19.4 Linked Lists
19.5 Stacks
19.6 Queues
19.7 Trees

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises • Special Section: Building Your Own Compiler

19.1 Introduction

We have studied such fixed-size *data structures* as single- and double-subscripted arrays. This chapter introduces *dynamic data structures* that grow and shrink at execution time. *Linked lists* are collections of data items "lined up in a row"—insertions and deletions can be made anywhere in a linked list. *Stacks* are important in compilers and operating systems; insertions and deletions are made only at one end of a stack—its *top*. *Queues* represent waiting lines; insertions are made at the back (also referred to as the *tail*) of a queue and deletions are made from the front (also referred to as the *head*) of a queue. *Binary trees* facilitate high-speed searching and sorting of data, eliminating of duplicate data items efficiently, representing file system directories, compiling expressions into machine language and many other interesting applications.

We will discuss each of the major types of data structures and implement programs that create and manipulate them. We use classes, inheritance and composition to create and package these data structures for reusability and maintainability. In Chapter 20, "Java Utilities Package and Bit Manipulation," and Chapter 21, "Collections," we discuss Java's predefined classes that implement the data structures discussed in this chapter.

The chapter examples are practical programs that can be used in more advanced courses and in industrial applications. The exercises include a rich collection of useful applications.

We encourage you to attempt the major project described in the special section entitled *Building Your Own Compiler*. You have been using a Java compiler to translate your Java programs to bytecodes so that you could execute these programs on your computer. In this project, you will actually build your own compiler. It will read a file of statements written in a simple, yet powerful high-level language similar to early versions of the popular language Basic. Your compiler will translate these statements into a file of Simpletron Machine Language (SML) instructions—SML is the language you learned in the Chapter 7 special section, *Building Your Own Computer*. Your Simpletron Simulator program will then execute the SML program produced by your compiler! Implementing this project by using an object-oriented approach will give you a wonderful opportunity to exercise most of what you have learned in this book. The special section carefully walks you through the specifications of the high-level language and describes the algorithms you will need to con-

vert each type of high-level language statement into machine language instructions. If you enjoy being challenged, you might attempt the many enhancements to both the compiler and the Simpletron Simulator suggested in the exercises.

19.2 Self-Referential Classes

A *self-referential class* contains an instance variable that refers to another object of the same class type. For example, the definition

```
class Node {
   private int data;
   private Node nextNode;

   public Node( int data )          { /* constructor body */ }
   public void setData( int data ) { /* method body */ }
   public int getData()             { /* method body */ }
   public void setNext( Node next ) { /* method body */ }
   public Node getNext()            { /* method body */ }
}
```

defines class **Node**. This type has two **private** instance variables—integer **data** and **Node** reference **nextNode**. Member **nextNode** references an object of type **Node**, an object of the same type as the one being declared here—hence, the term "self-referential class." Member **nextNode** is a *link*—**nextNode** "links" an object of type **Node** to another object of the same type. Type **Node** also has five methods: a constructor that receives an integer to initialize **data**, a **setData** method to set the value **data**, a **getData** method to return the value of **data**, a **setNext** method to set the value of **nextNode** and a **getNext** method to return the value of member **nextNode**.

Programs can link self-referential objects together to form such useful data structures as lists, queues, stacks and trees. Figure 19.1 illustrates two self-referential objects linked together to form a list. A backslash—representing a **null** reference—is placed in the link member of the second self-referential object to indicate that the link does not refer to another object. The backslash is for illustration purposes; it does not correspond to the backslash character in Java. Normally, a **null** reference indicates the end of a data structure.

Common Programming Error 19.1

Not setting the link in the last node of a list to **null** *is a logic error.*

19.3 Dynamic Memory Allocation

Creating and maintaining dynamic data structures requires *dynamic memory allocation*—the ability for a program to obtain more memory space at execution time to hold new nodes and to release space no longer needed. As we have already learned, Java programs do not explicitly release dynamically allocated memory. Rather, Java performs automatic garbage collection on objects that are no longer referenced in a program.

The limit for dynamic memory allocation can be as large as the amount of available physical memory in the computer or the amount of available disk space in a virtual-memory system. Often, the limits are much smaller, because the computer's available memory must be shared among many applications.

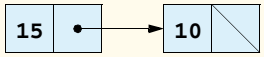


Fig. 19.1 Two self-referential class objects linked together.

Operator **new** is essential to dynamic memory allocation. Operator **new** takes as an operand the type of the object being dynamically allocated and returns a reference to a newly created object of that type. For example, the statement

```
Node nodeToAdd = new Node( 10 );
```

allocates the appropriate amount of memory to store a **Node** object and places a reference to this object in **nodeToAdd**. If no memory is available, **new** throws an **OutOfMemoryError**. The 10 is the **Node** object's data.

The following sections discuss lists, stacks, queues and trees that use dynamic memory allocation and self-referential classes to create dynamic data structures.

19.4 Linked Lists

A *linked list* is a linear collection (i.e., a sequence) of self-referential class objects, called *nodes,* connected by reference *links*—hence, the term "linked" list. A program accesses a linked list via a reference to the first node of the list. The program accesses each subsequent node via the link reference stored in the previous node. By convention, the link reference in the last node of a list is set to **null** to mark the end of the list. Data are stored in a linked list dynamically—the list creates each node as necessary. A node can contain data of any type, including objects of other classes. Stacks and queues are also linear data structures and, as we will see, are constrained versions of linked lists. Trees are nonlinear data structures.

Lists of data can be stored in arrays, but linked lists provide several advantages. A linked list is appropriate when the number of data elements to be represented in the data structure is unpredictable. Linked lists are dynamic, so the length of a list can increase or decrease as necessary. The size of a "conventional" Java array, however, cannot be altered, because the array size is fixed at the time the program creates the array. "Conventional" arrays can become full. Linked lists become full only when the system has insufficient memory to satisfy dynamic storage allocation requests. Package **java.util** contains class **LinkedList** for implementing and manipulating linked lists that grow and shrink during program execution. We discuss class **LinkedList** in Chapter 21, "Collections."

Performance Tip 19.1

An array can be declared to contain more elements than the number of items expected, but this can waste memory. Linked lists can provide better memory utilization in these situations. Linked lists allow the program to adapt at runtime.

Performance Tip 19.2

Insertion into a linked list is fast—only two references have to be modified (after you have located the place to do the insertion). All existing nodes remain at their current locations in memory.

Linked lists can be maintained in sorted order simply by inserting each new element at the proper point in the list (it does, of course, take time to locate the proper insertion point). Existing list elements do not need to be moved.

Linked list nodes normally are not stored contiguously in memory. Rather, they are logically contiguous. Figure 19.2 illustrates a linked list with several nodes. This diagram presents a *singly-linked list*—each node contains one reference to the next node in the list. Often, linked lists are implemented as doubly-linked lists—each node contains a reference to the next node in the list and a reference to the previous node in the list. Java's **LinkedList** class (see Chapter 21) is a doubly-linked list implementation.

Performance Tip 19.3

Insertion and deletion in a sorted array can be time consuming—all the elements following the inserted or deleted element must be shifted appropriately.

Performance Tip 19.4

The elements of an array are stored contiguously in memory. This allows immediate access to any array element, because the address of any element can be calculated directly as its offset from the beginning of the array. Linked lists do not afford such immediate access to their elements—an element can be accessed only by traversing the list from the front.

Performance Tip 19.5

Using dynamic memory allocation (instead of arrays) for data structures that grow and shrink at execution time can save memory. Keep in mind, however, that references occupy space, and that dynamic memory allocation incurs the overhead of method calls.

The program of Fig. 19.3–Fig. 19.5 uses a **List** class to manipulate a list of miscellaneous object types. The **main** method of class **ListTest** (Fig. 19.5) creates a list of objects, inserts objects at the beginning of the list using method **insertAtFront**, inserts objects at the end of the list using method **insertAtBack**, deletes objects from the front of the list using method **removeFromFront** and deletes objects from the end of the list using method **removeFromBack**. After each insert and remove operation, **ListTest** calls **List** method **print** to display the current list contents. A detailed discussion of the program follows. If an attempt is made to remove an item from an empty list, an **EmptyListException** (Fig. 19.4) occurs.

The program of Fig. 19.3–Fig. 19.5 consists of four classes—**ListNode** (Fig. 19.3), **List** (Fig. 19.3), **EmptyListException** (Fig. 19.4) and **ListTest** (Fig. 19.5). The **List** and **ListNode** classes are placed in package **com.deitel.jhtp4.ch19**, so they can be reused throughout this chapter. Encapsulated in each **List** object is a linked list of **ListNode** objects. The **ListNode** class (lines 6–38 of Fig. 19.3) consists of package-access members **data** and **nextNode**. **ListNode** member **data** can refer to any **Object**. **ListNode** member **nextNode** stores a reference to the next **ListNode** object in the linked list.

[*Note*: Many of the classes in this chapter are defined in the package **com.deitel.jhtp4.ch19**. Each such class should be compiled with the **-d** command-line option to **javac**. When compiling the classes that are not in this package and when running the programs, be sure to use the **-classpath** option to **javac** and **java**, respectively.]

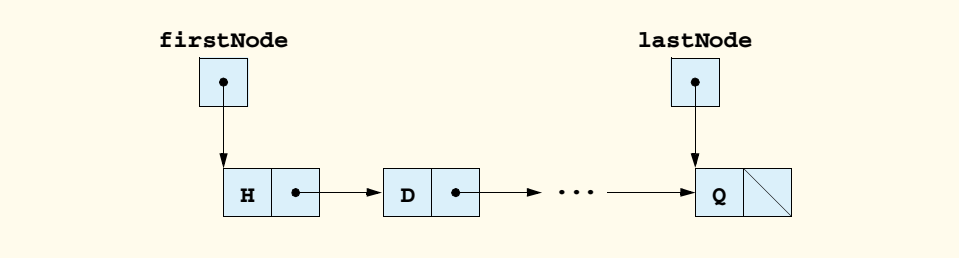


Fig. 19.2 A graphical representation of a linked list.

```
1  // Fig. 19.3: List.java
2  // Class ListNode and class List definitions
3  package com.deitel.jhtp4.ch19;
4
5  // class to represent one node in a list
6  class ListNode {
7
8     // package access members; List can access these directly
9     Object data;
10    ListNode nextNode;
11
12    // constructor to create a ListNode that refers to object
13    ListNode( Object object )
14    {
15       this( object, null );
16    }
17
18    // constructor to create ListNode that refers to Object
19    // and to next ListNode in List
20    ListNode( Object object, ListNode node )
21    {
22       data = object;
23       nextNode = node;
24    }
25
26    // return Object in this node
27    Object getObject()
28    {
29       return data;
30    }
31
32    // get next node
33    ListNode getNext()
34    {
35       return nextNode;
36    }
37
38 }  // end class ListNode
39
```

Fig. 19.3 Definitions of class **`ListNode`** and class **`List`** (part 1 of 4).

```
40  // class List definition
41  public class List {
42     private ListNode firstNode;
43     private ListNode lastNode;
44     private String name;  // String like "list" used in printing
45
46     // construct an empty List with a name
47     public List( String string )
48     {
49        name = string;
50        firstNode = lastNode = null;
51     }
52
53     // construct empty List with "list" as the name
54     public List()
55     {
56        this( "list" );
57     }
58
59     // Insert Object at front of List. If List is empty,
60     // firstNode and lastNode will refer to same object.
61     // Otherwise, firstNode refers to new node.
62     public synchronized void insertAtFront( Object insertItem )
63     {
64        if ( isEmpty() )
65           firstNode = lastNode = new ListNode( insertItem );
66
67        else
68           firstNode = new ListNode( insertItem, firstNode );
69     }
70
71     // Insert Object at end of List. If List is empty,
72     // firstNode and lastNode will refer to same Object.
73     // Otherwise, lastNode's nextNode refers to new node.
74     public synchronized void insertAtBack( Object insertItem )
75     {
76        if ( isEmpty() )
77           firstNode = lastNode = new ListNode( insertItem );
78
79        else
80           lastNode = lastNode.nextNode =
81              new ListNode( insertItem );
82     }
83
84     // remove first node from List
85     public synchronized Object removeFromFront()
86        throws EmptyListException
87     {
88        Object removeItem = null;
89
90        // throw exception if List is empty
91        if ( isEmpty() )
92           throw new EmptyListException( name );
```

Fig. 19.3 Definitions of class **`ListNode`** and class **`List`** (part 2 of 4).

```
93
94          // retrieve data being removed
95          removeItem = firstNode.data;
96
97          // reset the firstNode and lastNode references
98          if ( firstNode == lastNode )
99             firstNode = lastNode = null;
100
101         else
102            firstNode = firstNode.nextNode;
103
104         // return removed node data
105         return removeItem;
106      }
107
108      // Remove last node from List
109      public synchronized Object removeFromBack()
110         throws EmptyListException
111      {
112         Object removeItem = null;
113
114         // throw exception if List is empty
115         if ( isEmpty() )
116            throw new EmptyListException( name );
117
118         // retrieve data being removed
119         removeItem = lastNode.data;
120
121         // reset firstNode and lastNode references
122         if ( firstNode == lastNode )
123            firstNode = lastNode = null;
124
125         else {
126
127            // locate new last node
128            ListNode current = firstNode;
129
130            // loop while current node does not refer to lastNode
131            while ( current.nextNode != lastNode )
132               current = current.nextNode;
133
134            // current is new lastNode
135            lastNode = current;
136            current.nextNode = null;
137         }
138
139         // return removed node data
140         return removeItem;
141      }
142
143      // return true if List is empty
144      public synchronized boolean isEmpty()
145      {
```

Fig. 19.3 Definitions of class **`ListNode`** and class **`List`** (part 3 of 4).

```
146        return firstNode == null;
147     }
148
149     // output List contents
150     public synchronized void print()
151     {
152        if ( isEmpty() ) {
153           System.out.println( "Empty " + name );
154           return;
155        }
156
157        System.out.print( "The " + name + " is: " );
158
159        ListNode current = firstNode;
160
161        // while not at end of list, output current node's data
162        while ( current != null ) {
163           System.out.print( current.data.toString() + " " );
164           current = current.nextNode;
165        }
166
167        System.out.println( "\n" );
168     }
169
170  }  // end class List
```

Fig. 19.3 Definitions of class **`ListNode`** and class **`List`** (part 4 of 4).

Class **`List`** contains **`private`** members **`firstNode`** (a reference to the first **`ListNode`** in a **`List`**) and **`lastNode`** (a reference to the last **`ListNode`** in a **`List`**). The constructors (lines 47–51 and 54–57) initialize both references to **`null`**. The most important methods of class **`List`** are the **`synchronized`** methods **`insertAtFront`** (lines 62–69), **`insertAtBack`** (lines 74–82), **`removeFromFront`** (lines 85–106) and **`removeFromBack`** (lines 109–141). These methods are declared **`synchronized`** so **`List`** objects can be *multithread safe* when used in a multithreaded program. If one thread is modifying the contents of a **`List`**, no other thread can modify the same **`List`** object at the same time. Method **`isEmpty`** (lines 144–147) is a *predicate method* that determines whether the list is empty (i.e., the reference to the first node of the list is **`null`**). Predicate methods typically test a condition and do not modify the object on which they are called. If the list is empty, method **`isEmpty`** returns **`true`**; otherwise, it returns **`false`**. Method **`print`** (lines 150–168) displays the list's contents. Both **`isEmpty`** and **`print`** are also **`synchronized`** methods.

```
1  // Fig. 19.4: EmptyListException.java
2  // Class EmptyListException definition
3  package com.deitel.jhtp4.ch19;
4
5  public class EmptyListException extends RuntimeException {
6
```

Fig. 19.4 Definition of class **`EmptyListException`** (part 1 of 2).

```
7      // initialize an EmptyListException
8      public EmptyListException( String name )
9      {
10        super( "The " + name + " is empty" );
11     }
12
13  }  // end class EmptyListException
```

Fig. 19.4 Definition of class **EmptyListException** (part 2 of 2).

```
1  // Fig. 19.5: ListTest.java
2  // Class ListTest
3
4  // Deitel packages
5  import com.deitel.jhtp4.ch19.List;
6  import com.deitel.jhtp4.ch19.EmptyListException;
7
8  public class ListTest {
9
10    // test class List
11    public static void main( String args[] )
12    {
13       List list = new List();  // create the List container
14
15       // create objects to store in List
16       Boolean bool = Boolean.TRUE;
17       Character character = new Character( '$' );
18       Integer integer = new Integer( 34567 );
19       String string = "hello";
20
21       // use List insert methods
22       list.insertAtFront( bool );
23       list.print();
24       list.insertAtFront( character );
25       list.print();
26       list.insertAtBack( integer );
27       list.print();
28       list.insertAtBack( string );
29       list.print();
30
31       // use List remove methods
32       Object removedObject;
33
34       // remove objects from list; print after each removal
35       try {
36          removedObject = list.removeFromFront();
37          System.out.println(
38             removedObject.toString() + " removed" );
39          list.print();
40
```

Fig. 19.5 Manipulating a linked list.

```
41            removedObject = list.removeFromFront();
42            System.out.println(
43               removedObject.toString() + " removed" );
44            list.print();
45
46            removedObject = list.removeFromBack();
47            System.out.println(
48               removedObject.toString() + " removed" );
49            list.print();
50
51            removedObject = list.removeFromBack();
52            System.out.println(
53               removedObject.toString() + " removed" );
54            list.print();
55         }
56
57         // process exception if List is empty when attempt is
58         // made to remove an item
59         catch ( EmptyListException emptyListException ) {
60            emptyListException.printStackTrace();
61         }
62
63      }  // end method main
64
65   }  // end class ListTest
```

```
The list is: true

The list is: $ true

The list is: $ true 34567

The list is: $ true 34567 hello

$ removed
The list is: true 34567 hello

true removed
The list is: 34567 hello

hello removed
The list is: 34567

34567 removed
Empty list
```

Fig. 19.5 Manipulating a linked list.

Over the next several pages, we discuss each of the methods of class **`List`** (Fig. 19.3) in detail. Method **`insertAtFront`** (lines 62–69 of Fig. 19.3) places a new node at the front of the list. The method consists of several steps (Fig. 19.6 illustrates the operation):

1. Call **`isEmpty`** to determine whether the list is empty (line 64).

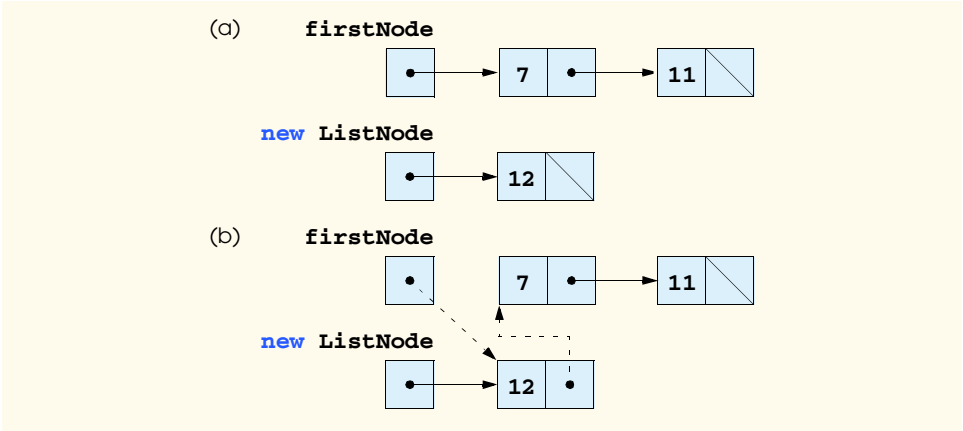


Fig. 19.6 The **insertAtFront** operation.

2. If the list is empty, both **firstNode** and **lastNode** are set to the **ListNode** allocated with **new** and initialized with **insertItem** (line 65). The **ListNode** constructor at lines 13–16 calls the **ListNode** constructor at lines 20–24 to set instance variable **data** to refer to the **insertItem** passed as an argument and to set reference **nextNode** to **null**.
3. If the list is not empty, the new node is "threaded" (not to be confused with multithreading) or "linked" into the list by setting **firstNode** to a new **ListNode** object and initializing that object with **insertItem** and **firstNode** (line 68). When the **ListNode** constructor (lines 20–24) executes, it sets instance variable **data** to refer to the **insertItem** passed as an argument and performs the insertion by setting the **nextNode** reference to the **ListNode** passed as an argument.

In Fig. 19.6, part (a) shows the list and the new node during the **insertAtFront** operation and before the program threads the new node into the list. The dotted arrows in part (b) illustrate step 3 of the **insertAtFront** operation that enables the node containing **12** to become the new list front.

Method **insertAtBack** (lines 74–82 of Fig. 19.3) places a new node at the back of the list. The method consists of several steps (Fig. 19.7 illustrates the operation):

1. Call **isEmpty** to determine whether the list is empty (line 76).
2. If the list is empty, both **firstNode** and **lastNode** are set to the **ListNode** allocated with **new** and initialized with **insertItem** (line 77). The **ListNode** constructor at lines 13–16 calls the **ListNode** constructor at lines 20–24 to set instance variable **data** to refer to the **insertItem** passed as an argument and to set reference **nextNode** to **null**.
3. If the list is not empty, the new node is threaded into the list by setting **LastNode** and **lastNode.nextNode** to the **ListNode** that was allocated with **new** and initialized with **insertItem** (lines 80–81). When the **ListNode** constructor (lines 13–16) executes, it sets instance variable **data** to refer to the **insertItem** passed as an argument and sets reference **nextNode** to **null**.

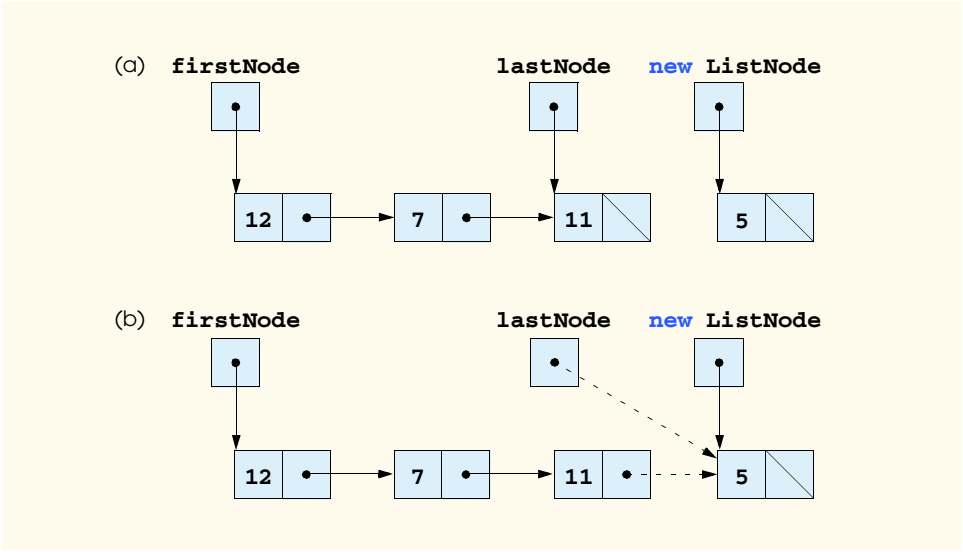


Fig. 19.7 A graphical representation of the **insertAtBack** operation.

In Fig. 19.7, part (a) shows the list and the new node during the **insertAtBack** operation and before the program threads the new node into the list. The dotted arrows in part (b) illustrate the steps of method **insertAtBack** that enable a new node to be added to the end of a list that is not empty.

Method **removeFromFront** (lines 85–106 of Fig. 19.3) removes the front node of the list and returns a reference to the removed data. The method throws an **EmptyListException** (lines 91–92) if the list is empty when the program calls this method. Otherwise, the method returns a reference to the removed data. The method consists of several steps (illustrated in Fig. 19.8):

1. Assign **firstNode.data** (the data being removed from the list) to reference **removeItem** (line 95).
2. If the objects to which **firstNode** and **lastNode** refer are equal (line 98), the list has only one element prior to the removal attempt. In this case, the method sets **firstNode** and **lastNode** to **null** (line 99) to "dethread" (remove) the node from the list (leaving the list empty).
3. If the list has more than one node prior to removal, then the method leaves reference **lastNode** as is and simply assigns **firstNode.nextNode** to reference **firstNode** (line 102). Thus, **firstNode** references the node that was the second node prior to the **removeFromFront** call.
4. Return the **removeItem** reference (line 105).

In Fig. 19.8, part (a) illustrates the list before the removal operation. Part (b) shows actual reference manipulations.

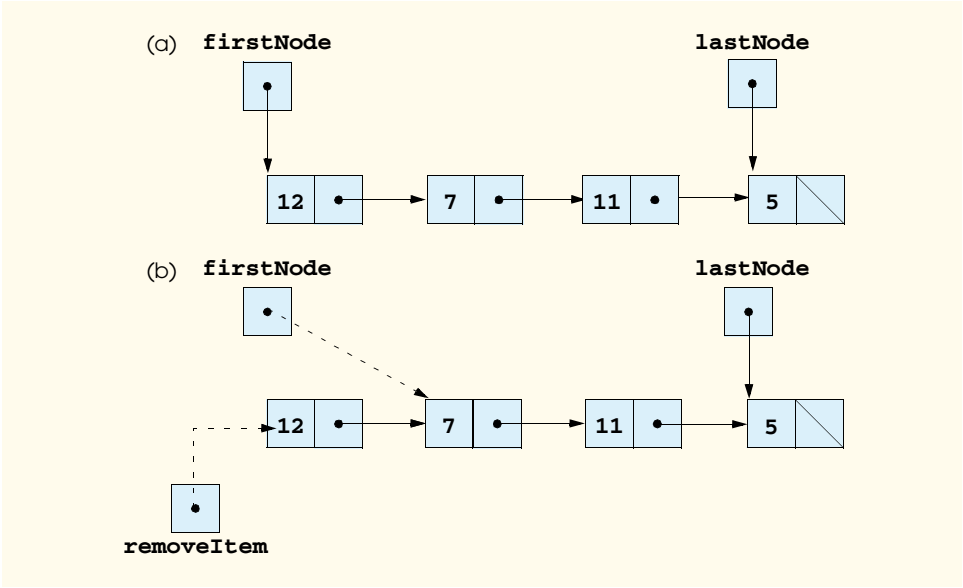


Fig. 19.8 A graphical representation of the **removeFromFront** operation.

Method **removeFromBack** (lines 109–141 of Fig. 19.3) removes the last node of a list and returns a reference to the removed data. The method throws an **EmptyListException** (lines 94 and 95) if the list is empty when the program calls this method. The method consists of several steps (Fig. 19.9 illustrates the operation):

1. Assign **lastNode.data** (the data being removed from the list) to reference **removeItem** (line 119).
2. If the objects to which **firstNode** and **lastNode** refer are equal (line 122), the list has only one element prior to the removal attempt. In this case, the method sets **firstNode** and **lastNode** to **null** (line 123) to dethread (remove) that node from the list (leaving the list empty).
3. If the list has more than one node prior to removal, then create the **ListNode** reference **current** and assign it **firstNode**.
4. Now "walk the list" with **current** until it references the node before the last node. The **while** loop (lines 131–132) assigns **current.nextNode** to **current** as long as **current.nextNode** is not **lastNode**.
5. After locating the second-to-last node, assign **current** to **lastNode** (line 135) to dethread the last node from the list.
6. Set the **current.nextNode** to **null** (line 136) to terminate the list at the current node.
7. Return the **removeItem** reference (liner 140).

In Fig. 19.9, part (a) illustrates the list before the removal operation. Part (b) shows the actual reference manipulations.

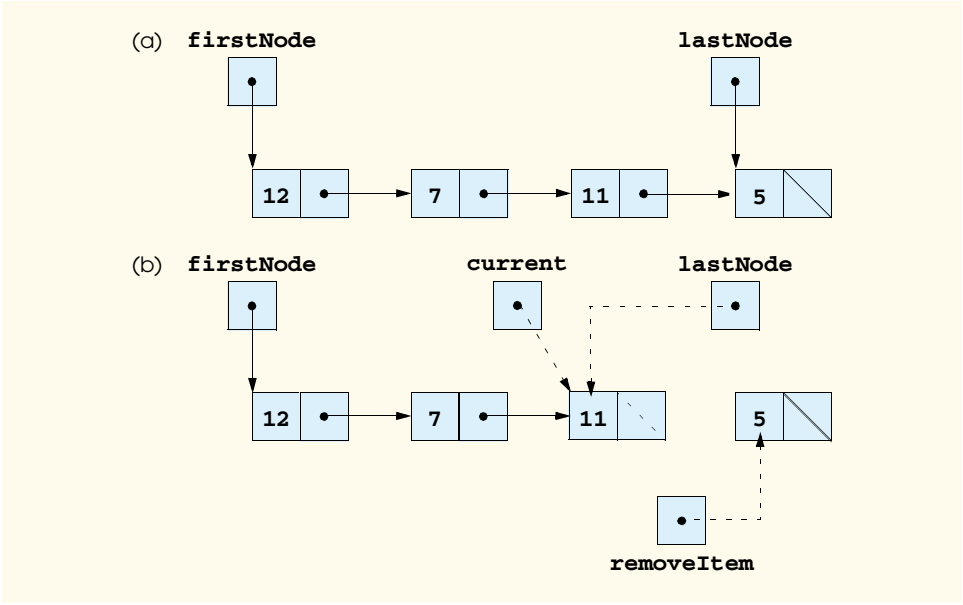


Fig. 19.9 A graphical representation of the **`removeFromBack`** operation.

Method **`print`** (lines 150–168) first determines whether the list is empty (lines 152–155). If so, **`print`** displays a message indicating that the list is empty and returns control to the calling method. Otherwise, **`print`** outputs the data in the list. Line 159 creates **`ListNode`** reference **`current`** and initializes it with **`firstNode`**. While **`current`** is not **`null`**, there are more items in the list. therefore, line 163 outputs a **`String`** representation of **`current.data`**. Line 164 moves to the next node in the list by assigning the value of **`current.nextNode`** to **`current`**. This printing algorithm is identical for linked lists, stacks and queues.

19.5 Stacks

A *stack* is a constrained version of a linked list—new nodes can be added to a stack and removed from a stack only at the top. For this reason, a stack is referred to as a *last-in, first-out* (*LIFO*) data structure. The link member in the bottom (i.e., last) node of the stack is set to **`null`** to indicate the bottom of the stack.

Common Programming Error 19.2

*Not setting the link in the bottom node of a stack to **`null`** is a common logic error.*

The primary methods used to manipulate a stack are ***`push`*** and ***`pop`***. Method **`push`** adds a new node to the top of the stack. Method **`pop`** removes a node from the top of the stack and returns the data from the popped node.

Stacks have many interesting applications. For example, when a program calls a method, the called method must know how to return to its caller, so the return address of the calling method is pushed onto the *program execution stack*. If a series of method calls

occurs, the successive return addresses are pushed onto the stack in last-in, first-out order so that each method can return to its caller. Stacks support recursive method calls in the same manner as they do conventional nonrecursive method calls.

The program execution stack contains the memory for local variables on each invocation of a method during a program's execution. When the method returns to its caller, the memory for that method's local variables is popped off the stack and those variables are no longer known to the program.

Compilers use stacks to evaluate arithmetic expressions and generate machine language code to process the expressions. The exercises in this chapter explore several applications of stacks, including using them to develop a complete working compiler. The **`java.util`** package of the Java API contains class **`Stack`** for implementing and manipulating stacks that can grow and shrink during program execution. We will discuss class **`Stack`** in Chapter 20.

We take advantage of the close relationship between lists and stacks to implement a stack class by reusing a list class. We demonstrate two different forms of reusability. First, we implement the stack class by extending class **`List`** of Fig. 19.3. Then we implement an identically performing stack class through composition by including a **`List`** object as a **`private`** member of a stack class. The list, stack and queue data structures in this chapter are implemented to store **`Object`** references to encourage further reusability. Thus, any object type can be stored in a list, stack or queue.

The application of Fig. 19.10 and Fig. 19.11 creates a stack class by extending class **`List`** of Fig. 19.3. We want the stack to have methods **`push`**, **`pop`**, **`isEmpty`** and **`print`**. Essentially, these are the methods **`insertAtFront`**, **`removeFromFront`**, **`isEmpty`** and **`print`** of class **`List`**. Of course, class **`List`** contains other methods (such as **`insertAtBack`** and **`removeFromBack`**) that we would rather not make accessible through the **`public`** interface to the stack class. It is important to remember that all methods in the **`public`** interface of class **`List`** class also are **`public`** methods of the subclass **`StackInheritance`** (Fig. 19.10). When we implement the stack's methods, we have each **`StackInheritance`** method call the appropriate **`List`** method—method **`push`** calls **`insertAtFront`** and method **`pop`** calls **`removeFromFront`**. Class **`StackInheritance`** is defined as part of package **`com.deitel.jhtp4.ch19`** for reuse purposes. Note that **`StackInheritance`** does not import **`List`**, because both classes are in the same package.

```
1  // Fig. 19.10: StackInheritance.java
2  // Derived from class List
3  package com.deitel.jhtp4.ch19;
4
5  public class StackInheritance extends List {
6
7     // construct stack
8     public StackInheritance()
9     {
10       super( "stack" );
11    }
12
```

Fig. 19.10 Class **`StackInheritance`** extends class **`List`** (part 1 of 2).

```
13     // add object to stack
14     public synchronized void push( Object object )
15     {
16        insertAtFront( object );
17     }
18
19     // remove object from stack
20     public synchronized Object pop() throws EmptyListException
21     {
22        return removeFromFront();
23     }
24
25  }  // end class StackInheritance
```

Fig. 19.10 Class **StackInheritance** extends class **List** (part 2 of 2).

Class **StackInheritanceTest**'s method **main** (Fig. 19.11) uses class **StackInheritance** to instantiate a stack of **Object**s called **stack**. The program pushes onto the stack (lines 22, 24, 26 and 28) a **Boolean** object containing **true**, a **Character** object containing **$**, an **Integer** object containing **34567** and a **String** object containing **hello**, then popped off **stack**. Lines 37–42 pop the objects from the stack in an infinite **while** loop. When there are no objects left to pop, an method **pop** throws an **EmptyListException**, and the program displays the exception's stack trace, which shows the methods on the program execution stack at the time the exception occurred. Note that the program uses method **print** (inherited from **List**) to output the contents of the stack.

```
1  // Fig. 19.11: StackInheritanceTest.java
2  // Class StackInheritanceTest
3
4  // Deitel packages
5  import com.deitel.jhtp4.ch19.StackInheritance;
6  import com.deitel.jhtp4.ch19.EmptyListException;
7
8  public class StackInheritanceTest {
9
10    // test class StackInheritance
11    public static void main( String args[] )
12    {
13       StackInheritance stack = new StackInheritance();
14
15       // create objects to store in the stack
16       Boolean bool = Boolean.TRUE;
17       Character character = new Character( '$' );
18       Integer integer = new Integer( 34567 );
19       String string = "hello";
20
21       // use push method
22       stack.push( bool );
23       stack.print();
24       stack.push( character );
```

Fig. 19.11 A simple stack program (part 1 of 2).

```
25          stack.print();
26          stack.push( integer );
27          stack.print();
28          stack.push( string );
29          stack.print();
30
31          // remove items from stack
32          try {
33
34             // use pop method
35             Object removedObject = null;
36
37             while ( true ) {
38                removedObject = stack.pop();
39                System.out.println( removedObject.toString() +
40                   " popped" );
41                stack.print();
42             }
43          }
44
45          // catch exception if stack empty when item popped
46          catch ( EmptyListException emptyListException ) {
47             emptyListException.printStackTrace();
48          }
49
50       }  // end method main
51
52    }  // end class StackInheritanceTest
```

```
The stack is: true

The stack is: $ true

The stack is: 34567 $ true

The stack is: hello 34567 $ true

hello popped
The stack is: 34567 $ true

34567 popped
The stack is: $ true

$ popped
The stack is: true

true popped
Empty stack
com.deitel.jhtp4.ch19.EmptyListException: The stack is empty
        at com.deitel.jhtp4.ch19.List.removeFromFront(List.java:92)
        at com.deitel.jhtp4.ch19.StackInheritance.pop(
           StackInheritance.java:22)
        at StackInheritanceTest.main(StackInheritanceTest.java:38)
```

Fig. 19.11 A simple stack program (part 2 of 2).

Another way to implement a stack class is by reusing a list class through composition. The class in Fig. 19.12 uses a **private** object of class **List** (line 6) in the definition of class **StackComposition**. Composition enables us to hide the methods of class **List** that should not be in our stack's **public** interface by providing **public** interface methods only to the required **List** methods. This technique of implementing each stack method as a call to a **List** method is called *delegating*—the stack method invoked *delegates* the call to the appropriate **List** method. In particular, **StackComposition** delegates calls to **List** methods **insertAtFront**, **removeFromFront**, **isEmpty** and **print**. In this example, we do not show class **StackCompositionTest**, because the only difference in this example is that we change the type of the stack from **StackInheritance** to **StackComposition**. If you execute the application from the code on the CD that accompanies this book, you will see that the output is identical.

```
1  // Fig. 19.12: StackComposition.java
2  // Class StackComposition definition with composed List object
3  package com.deitel.jhtp4.ch19;
4
5  public class StackComposition {
6     private List stackList;
7
8     // construct stack
9     public StackComposition()
10    {
11       stackList = new List( "stack" );
12    }
13
14    // add object to stack
15    public synchronized void push( Object object )
16    {
17       stackList.insertAtFront( object );
18    }
19
20    // remove object from stack
21    public synchronized Object pop() throws EmptyListException
22    {
23       return stackList.removeFromFront();
24    }
25
26    // determine if stack is empty
27    public synchronized boolean isEmpty()
28    {
29       return stackList.isEmpty();
30    }
31
32    // output stack contents
33    public synchronized void print()
34    {
35       stackList.print();
36    }
37
38 }  // end class StackComposition
```

Fig. 19.12 A simple stack class using composition.

19.6 Queues

Another common data structure is the *queue*. A queue is similar to a checkout line in a supermarket—the cashier services the person at the beginning of the line first. Other customers enter the line only at the end and wait for service. Queue nodes are removed only from the *head* (or front) of the queue and are inserted only at the *tail* (or end) of the queue. For this reason, a queue is a *first-in, first-out (FIFO)* data structure. The insert and remove operations are known as ***enqueue*** and ***dequeue***.

Queues have many applications in computer systems. Most computers have only a single processor, so only one application at a time can be serviced. Entries for the other applications are placed in a queue. The entry at the front of the queue is the next to receive service. Each entry gradually advances to the front of the queue as applications receive service.

Queues are also used to support print spooling. A multiuser environment may have only a single printer. Many users may send print jobs to the printer. Even when the printer is busy, other people may still send print jobs. These are "spooled" to disk (much as thread is wound onto a spool) where they wait in a queue until the printer becomes available.

Information packets also wait in queues in computer networks. Each time a packet arrives at a network node, it must be routed to the next node on the network along the path to the packet's final destination. The routing node routes one packet at a time, so additional packets are enqueued until the router can route them.

A file server in a computer network handles file-access requests from many clients throughout the network. Servers have a limited capacity to service requests from clients. When that capacity is exceeded, client requests wait in queues.

The application of Fig. 19.13 and Fig. 19.14 creates a queue by extending class **`List`** (Fig. 19.3). We want class **`QueueInheritance`** (Fig. 19.13) to have methods **`enqueue`** and **`dequeue`**, **`isEmpty`** and **`print`**. Note that these are essentially the **`List`** methods **`insertAtBack`** and **`removeFromFront`**. Of course, class **`List`** contains other methods (i.e., **`insertAtFront`** and **`removeFromBack`**) that we would rather not make accessible through the **`public`** interface of the queue. Remember that all methods in the **`public`** interface of the **`List`** class are also **`public`** methods of the subclass **`QueueInheritance`**. In the queue's implementation, each method of class **`QueueInheritance`** calls the appropriate **`List`** method—method **`enqueue`** calls **`insertAtBack`** and method **`dequeue`** calls **`removeFromFront`**. Class **`QueueInheritance`** is defined in package **`com.deitel.jhtp4.ch19`** for reuse purposes.

Common Programming Error 19.3

*Not setting the link in the last node of a queue to **`null`** is a common logic error.*

```
1  // Fig. 19.13: QueueInheritance.java
2  // Class QueueInheritance extends class List
3
4  // Deitel packages
5  package com.deitel.jhtp4.ch19;
6
7  public class QueueInheritance extends List {
8
```

Fig. 19.13 Class **`QueueInheritance`** extends class **`List`** (part 1 of 2).

```
 9     // construct queue
10     public QueueInheritance()
11     {
12        super( "queue" );
13     }
14
15     // add object to queue
16     public synchronized void enqueue( Object object )
17     {
18        insertAtBack( object );
19     }
20
21     // remove object from queue
22     public synchronized Object dequeue() throws EmptyListException
23     {
24        return removeFromFront();
25     }
26
27  }  // end class QueueInheritance
```

Fig. 19.13 Class **QueueInheritance** extends class **List** (part 2 of 2).

Class **QueueInheritanceTest** method **main** (Fig. 19.14) uses class **QueueInheritance** to instantiate a queue of **Object**s called **queue**. Lines 22, 24, 26 and 28 enqueue a **Boolean** object containing **true**, a **Character** object containing **$**, an **Integer** object containing **34567** and a **String** object containing **hello**. Lines 37–42 use an infinite **while** loop to dequeue the objects in first-in, first-out order. When there are no objects left to dequeue, method dequeue throws an **EmptyListException**, and the program displays the exception's stack trace.

```
 1  // Fig. 19.14: QueueInheritanceTest.java
 2  // Class QueueInheritanceTest
 3
 4  // Deitel packages
 5  import com.deitel.jhtp4.ch19.QueueInheritance;
 6  import com.deitel.jhtp4.ch19.EmptyListException;
 7
 8  public class QueueInheritanceTest {
 9
10     // test class QueueInheritance
11     public static void main( String args[] )
12     {
13        QueueInheritance queue = new QueueInheritance();
14
15        // create objects to store in queue
16        Boolean bool = Boolean.TRUE;
17        Character character = new Character( '$' );
18        Integer integer = new Integer( 34567 );
19        String string = "hello";
```

Fig. 19.14 Processing a queue (part 1 of 3).

```
20
21          // use enqueue method
22          queue.enqueue( bool );
23          queue.print();
24          queue.enqueue( character );
25          queue.print();
26          queue.enqueue( integer );
27          queue.print();
28          queue.enqueue( string );
29          queue.print();
30
31          // remove objects from queue
32          try {
33
34             // use dequeue method
35             Object removedObject = null;
36
37             while ( true ) {
38                removedObject = queue.dequeue();
39                System.out.println( removedObject.toString() +
40                   " dequeued" );
41                queue.print();
42             }
43          }
44
45          // process exception if queue empty when item removed
46          catch ( EmptyListException emptyListException ) {
47             emptyListException.printStackTrace();
48          }
49
50       }  // end method main
51
52    }  // end class QueueInheritanceTest
```

```
The queue is: true

The queue is: true $

The queue is: true $ 34567

The queue is: true $ 34567 hello

true dequeued
The queue is: $ 34567 hello

$ dequeued
The queue is: 34567 hello

34567 dequeued
The queue is: hello

hello dequeued
Empty queue
```

(continued on next page)

Fig. 19.14 Processing a queue (part 2 of 3).

(continued from previous page)

```
com.deitel.jhtp4.ch19.EmptyListException: The queue is empty
        at com.deitel.jhtp4.ch19.List.removeFromFront(List.java:92)
        at com.deitel.jhtp4.ch19.QueueInheritance.dequeue(
           QueueInheritance.java:24)
        at QueueInheritanceTest.main(QueueInheritanceTest.java:38)
```

Fig. 19.14 Processing a queue (part 3 of 3).

19.7 Trees

Linked lists, stacks and queues are *linear data structures* (i.e., *sequences*). A tree is a non-linear, two-dimensional data structure with special properties. Tree nodes contain two or more links. This section discusses *binary trees* (Fig. 19.15)—trees whose nodes all contain two links (none, one or both of which may be **`null`**). The *root node* is the first node in a tree. Each link in the root node refers to a *child.* The *left child* is the first node in the *left subtree,* and the *right child* is the first node in the *right subtree.* The children of a specific node are called *siblings*. A node with no children is called a *leaf node.* Computer scientists normally draw trees from the root node down—exactly the opposite of the way most trees grow in nature.

Common Programming Error 19.4

Not setting to **`null`** *the links in leaf nodes of a tree is a common logic error.*

In our binary tree example, we create a special binary tree called a *binary search tree*. A binary search tree (with no duplicate node values) has the characteristic that the values in any left subtree are less than the value in the subtree's parent node, and the values in any right subtree are greater than the value in the subtree's parent node. Figure 19.16 illustrates a binary search tree with 12 integer values. Note that the shape of the binary search tree that corresponds to a set of data can vary, depending on the order in which the values are inserted into the tree.

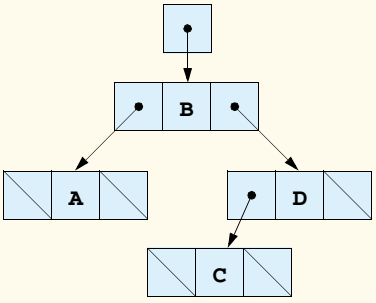


Fig. 19.15 A graphical representation of a binary tree.

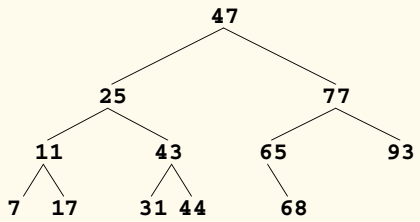


Fig. 19.16 A binary search tree containing 12 values.

The application of Fig. 19.17 and Fig. 19.18 creates a binary search tree of integers and traverses it (i.e., walks through all its nodes) three ways—using recursive *inorder*, *preorder* and *postorder traversals*. The program generates 10 random numbers and inserts each into the tree. Class **`Tree`** is defined in package **`com.deitel.jhtp4.ch19`** for reuse purposes.

```
1  // Fig. 19.17: Tree.java
2  // Definition of class TreeNode and class Tree.
3
4  // Deitel packages
5  package com.deitel.jhtp4.ch19;
6
7  // class TreeNode definition
8  class TreeNode {
9
10    // package access members
11    TreeNode leftNode;
12    int data;
13    TreeNode rightNode;
14
15    // initialize data and make this a leaf node
16    public TreeNode( int nodeData )
17    {
18       data = nodeData;
19       leftNode = rightNode = null;  // node has no children
20    }
21
22    // insert TreeNode into Tree that contains nodes;
23    // ignore duplicate values
24    public synchronized void insert( int insertValue )
25    {
26       // insert in left subtree
27       if ( insertValue < data ) {
28
29          // insert new TreeNode
30          if ( leftNode == null )
31             leftNode = new TreeNode( insertValue );
32
```

Fig. 19.17 Definitions of **`TreeNode`** and **`Tree`** for a binary search tree (part 1 of 4).

```
33             // continue traversing left subtree
34             else
35                leftNode.insert( insertValue );
36          }
37
38          // insert in right subtree
39          else if ( insertValue > data ) {
40
41             // insert new TreeNode
42             if ( rightNode == null )
43                rightNode = new TreeNode( insertValue );
44
45             // continue traversing right subtree
46             else
47                rightNode.insert( insertValue );
48          }
49
50       }  // end method insert
51
52    }  // end class TreeNode
53
54    // class Tree definition
55    public class Tree {
56       private TreeNode root;
57
58       // construct an empty Tree of integers
59       public Tree()
60       {
61          root = null;
62       }
63
64       // Insert a new node in the binary search tree.
65       // If the root node is null, create the root node here.
66       // Otherwise, call the insert method of class TreeNode.
67       public synchronized void insertNode( int insertValue )
68       {
69          if ( root == null )
70             root = new TreeNode( insertValue );
71
72          else
73             root.insert( insertValue );
74       }
75
76       // begin preorder traversal
77       public synchronized void preorderTraversal()
78       {
79          preorderHelper( root );
80       }
81
82       // recursive method to perform preorder traversal
83       private void preorderHelper( TreeNode node )
84       {
```

Fig. 19.17 Definitions of **`TreeNode`** and **`Tree`** for a binary search tree (part 2 of 4).

```
85          if ( node == null )
86             return;
87
88          // output node data
89          System.out.print( node.data + " " );
90
91          // traverse left subtree
92          preorderHelper( node.leftNode );
93
94          // traverse right subtree
95          preorderHelper( node.rightNode );
96       }
97
98       // begin inorder traversal
99       public synchronized void inorderTraversal()
100      {
101         inorderHelper( root );
102      }
103
104      // recursive method to perform inorder traversal
105      private void inorderHelper( TreeNode node )
106      {
107         if ( node == null )
108            return;
109
110         // traverse left subtree
111         inorderHelper( node.leftNode );
112
113         // output node data
114         System.out.print( node.data + " " );
115
116         // traverse right subtree
117         inorderHelper( node.rightNode );
118      }
119
120      // begin postorder traversal
121      public synchronized void postorderTraversal()
122      {
123         postorderHelper( root );
124      }
125
126      // recursive method to perform postorder traversal
127      private void postorderHelper( TreeNode node )
128      {
129         if ( node == null )
130            return;
131
132         // traverse left subtree
133         postorderHelper( node.leftNode );
134
135         // traverse right subtree
136         postorderHelper( node.rightNode );
137
```

Fig. 19.17 Definitions of **`TreeNode`** and **`Tree`** for a binary search tree (part 3 of 4).

```
138         // output node data
139         System.out.print( node.data + " " );
140      }
141
142   }  // end class Tree
```

Fig. 19.17 Definitions of **TreeNode** and **Tree** for a binary search tree (part 4 of 4).

Let us walk through the binary tree program. Method **main** of class **TreeTest** (Fig. 19.18) begins by instantiating an empty **Tree** object and storing it in reference **tree** (line 11). The program randomly generates 10 integers, each of which is inserted into the binary tree through a call to **synchronized** method **insertNode** (line 21). The program then performs preorder, inorder and postorder traversals (these will be explained shortly) of **tree**.

```
1  // Fig. 19.18: TreeTest.java
2  // This program tests class Tree.
3  import com.deitel.jhtp4.ch19.Tree;
4
5  // Class TreeTest definition
6  public class TreeTest {
7
8     // test class Tree
9     public static void main( String args[] )
10    {
11       Tree tree = new Tree();
12       int value;
13
14       System.out.println( "Inserting the following values: " );
15
16       // insert 10 random integers from 0-99 in tree
17       for ( int i = 1; i <= 10; i++ ) {
18          value = ( int ) ( Math.random() * 100 );
19          System.out.print( value + " " );
20
21          tree.insertNode( value );
22       }
23
24       // perform preorder traveral of tree
25       System.out.println ( "\n\nPreorder traversal" );
26       tree.preorderTraversal();
27
28       // perform inorder traveral of tree
29       System.out.println ( "\n\nInorder traversal" );
30       tree.inorderTraversal();
31
32       // perform postorder traveral of tree
33       System.out.println ( "\n\nPostorder traversal" );
34       tree.postorderTraversal();
35       System.out.println();
36    }
```

Fig. 19.18 Creating and traversing a binary tree (part 1 of 2).

```
37
38   }  // end class TreeTest
```

```
Inserting the following values:
39 69 94 47 50 72 55 41 97 73

Preorder traversal
39 69 47 41 50 55 94 72 73 97

Inorder traversal
39 41 47 50 55 69 72 73 94 97

Postorder traversal
41 55 50 47 73 72 97 94 69 39
```

Fig. 19.18 Creating and traversing a binary tree (part 2 of 2).

Class **Tree** (lines 55–142 of Fig. 19.17) has as **private** data **root**—a reference to the root node of the tree. The class contains **public** method **insertNode** (lines 67–74) to insert a new node in the tree and **public** methods **preorderTraversal** (lines 77–80), **inorderTraversal** (lines 99–102) and **postorderTraversal** (lines 121–124) to begin traversals of the tree. Each of these methods calls a separate recursive utility method to perform the traversal operations on the internal representation of the tree. The **Tree** constructor (lines 59–62) initializes **root** to **null** to indicate that the tree is empty.

The **Tree** class's **synchronized** method **insertNode** (lines 67–74) first determines if the tree is empty. If so, it allocates a new **TreeNode**, initializes the node with the integer being inserted in the tree and assigns the new node to the **root** reference (line 70). If the tree is not empty, insertNode calls **TreeNode** method **insert** (lines 24–52). This method uses recursion to determine the location for the new node in the tree and inserts the node at that location. *A node can be inserted only as a leaf node in a binary search tree.*

The **TreeNode** method **insert** compares the value to insert with the **data** value in the root node. If the insert value is less than the root node data, the program determines if the left subtree is empty (line 30). If so, line 31 allocates a new **TreeNode**, initializes it with the integer being inserted and assigns the new node to reference **leftNode**. Otherwise, line 35 recursively calls **insert** for the left subtree to insert the value into the left subtree. If the insert value is greater than the root node data, the program determines if the right subtree is empty (line 42). If so, line 43 allocates a new **TreeNode**, initializes it with the integer being inserted and assigns the new node to reference **rightNode**. Otherwise, line 47 recursively calls **insert** for the right subtree to insert the value in the right subtree.

Methods **inorderTraversal**, **preorderTraversal** and **postorderTraversal** call helper methods **inorderHelper** (lines 105–118), **preorderHelper** (lines 83–96) and **postorderHelper** (lines 127–140), respectively, to traverse the tree (Fig. 19.19) and print the node values. The purpose of the helper methods in class **Tree** is to allow the programmer to start a traversal without the need to obtain a reference to the **root** node first, then call the recursive method with that reference. Methods **inorderTraversal**, **preorderTraversal** and **postorderTraversal** simply take the **private root** reference and pass it to the appropriate helper method to initiate a traversal of the tree.

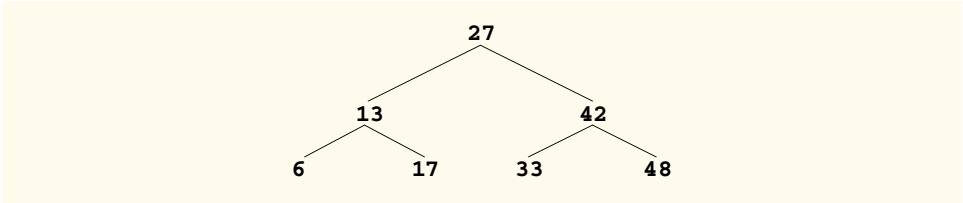


Fig. 19.19 A binary search tree.

Method **inorderHelper** (lines 105–118) defines the steps for an inorder traversal. Those steps are as follows:

1. Traverse the left subtree with a call to **inorderHelper** (line 111).
2. Process the value in the node (line 114).
3. Traverse the right subtree with a call to **inorderHelper** (line 117).

The inorder traversal does not process the value in a node until the values in that node's left subtree are processed. The inorder traversal of the tree in Fig. 19.19 is

```
6 13 17 27 33 42 48
```

Note that the inorder traversal of a binary search tree prints the node values in ascending order. The process of creating a binary search tree actually sorts the data—and thus, this process is called the *binary tree sort*.

Method **preorderHelper** (lines 83–96) defines the steps for a preorder traversal. Those steps are as follows:

1. Process the value in the node (line 89).
2. Traverse the left subtree with a call to **preorderHelper** (line 92).
3. Traverse the right subtree with a call to **preorderHelper** (line 95).

The preorder traversal processes the value in each node as the node is visited. After processing the value in a given node, the preorder traversal processes the values in the left subtree, then the values in the right subtree. The preorder traversal of the tree in Fig. 19.19 is

```
27 13 6 17 42 33 48
```

Method **postorderHelper** (lines 127–140) defines the steps for a postorder traversal. Those steps are as follows:

1. Traverse the left subtree with a **postorderHelper** (line 133).
2. Traverse the right subtree with a **postorderHelper** (line 136).
3. Process the value in the node (line 139).

The postorder traversal processes the value in each node after the values of all that node's children are processed. The **postorderTraversal** of the tree in Fig. 19.19 is

```
6 17 13 33 48 42 27
```

The binary search tree facilitates *duplicate elimination.* While building a tree, the insertion operation recognizes attempts to insert a duplicate value, because a duplicate follows

the same "go left" or "go right" decisions on each comparison as the original value did. Thus, the insertion operation eventually compares the duplicate with a node containing the same value. At this point, the insertion operation might simply discard the duplicate value.

Searching a binary tree for a value that matches a key value is fast, especially for *tightly packed* trees. In a tightly packed tree, each level contains about twice as many elements as the previous level. Figure 19.19 is a tightly packed binary tree. A binary search tree with n elements has a minimum of $\log_2 n$ levels. Thus, at most $\log_2 n$ comparisons are required either to find a match or to determine that no match exists. Searching a (tightly packed) 1000-element binary search tree requires at most 10 comparisons, because $2^{10} > 1000$. Searching a (tightly packed) 1,000,000-element binary search tree requires at most 20 comparisons, because $2^{20} > 1{,}000{,}000$.

The chapter exercises present algorithms for several other binary tree operations, such as deleting an item from a binary tree, printing a binary tree in a two-dimensional tree format and performing a *level-order traversal of a binary tree*. The level-order traversal of a binary tree visits the nodes of the tree row-by-row, starting at the root node level. On each level of the tree, a level-order traversal visits the nodes from left to right. Other binary tree exercises include allowing a binary search tree to contain duplicate values, inserting string values in a binary tree and determining how many levels are contained in a binary tree.

SUMMARY

- Dynamic data structures can grow and shrink at execution time.
- Linked lists are collections of data items "lined up in a row"—insertions and deletions can be made anywhere in a linked list.
- Stacks are important in compilers and operating systems—insertions and deletions are made only at one end of a stack, its top.
- Queues represent waiting lines; insertions are made at the back (also referred to as the tail) of a queue and deletions are made from the front (also referred to as the head) of a queue.
- Binary trees facilitate high-speed searching and sorting of data, eliminating duplicate data items efficiently, representing file system directories and compiling expressions into machine language.
- A self-referential class contains a reference that refers to another object of the same class type. Self-referential objects can be linked together to form useful data structures such as lists, queues, stacks and trees.
- Creating and maintaining dynamic data structures requires dynamic memory allocation—the ability for a program to obtain more memory space at execution time to hold new nodes and to release space no longer needed.
- The limit for dynamic memory allocation can be as large as the available physical memory in the computer or the amount of available disk space in a virtual-memory system. Often, the limits are much smaller because the computer's available memory must be shared among many users.
- Operator **`new`** takes as an operand the type of the object being dynamically allocated and returns a reference to a newly created object of that type. If no memory is available, **`new`** throws an **`OutOfMemoryError`**.
- A linked list is a linear collection (i.e., a sequence) of self-referential class objects, called nodes, connected by reference links.
- A linked list is accessed via a reference to the first node of the list. Each subsequent node is accessed via the link-reference member stored in the previous node.

- By convention, the link reference in the last node of a list is set to **`null`** to mark the end of the list.
- A node can contain data of any type, including objects of other classes.
- Trees are nonlinear data structures.
- A linked list is appropriate when the number of data elements to be represented in the data structure is unpredictable. Linked lists are dynamic, so the length of a list can increase or decrease as necessary.
- The size of a "conventional" Java array cannot be altered—the size is fixed at creation time.
- Linked lists can be maintained in sorted order simply by inserting each new element at the proper point in the list.
- List nodes are normally not stored contiguously in memory. Rather, they are logically contiguous.
- Methods that manipulate the contents of a list should be declared **`synchronized`** so list objects can be *multithread safe* when used in a multithreaded program. If one thread is modifying the contents of a list, no other thread is allowed to modify the same list at the same time.
- A stack is a constrained version of a linked list—new nodes can be added to a stack and removed from a stack only at the top. A stack is referred to as a last-in, first-out (LIFO) data structure.
- The primary methods used to manipulate a stack are **`push`** and **`pop`**. Method **`push`** adds a new node to the top of the stack. Method **`pop`** removes a node from the top of the stack and returns the **`data`** object from the popped node.
- Stacks have many interesting applications. When a method call is made, the called method must know how to return to its caller, so the return address is pushed onto the program execution stack. If a series of method calls occurs, the successive return values are pushed onto the stack in last-in, first-out order so that each method can return to its caller.
- The program execution stack contains the space created for local variables on each invocation of a method. When the method returns to its caller, the space for that method's local variables is popped off the stack, and those variables are no longer known to the program.
- Stacks are also used by compilers in the process of evaluating arithmetic expressions and generating machine language code to process the expressions.
- The technique of implementing each stack method as a call to a **`List`** method is called delegating—the stack method invoked delegates the call to the appropriate **`List`** method.
- A queue is a constrained version of a list.
- A queue is similar to a checkout line in a supermarket—the first person in line is serviced first, and other customers enter the line only at the end and wait to be serviced.
- Queue nodes are removed only from the head of the queue and are inserted only at the tail of the queue. For this reason, a queue is referred to as a first-in, first-out (FIFO) data structure.
- The insert and remove operations for a queue are known as **`enqueue`** and **`dequeue`**.
- Queues have many applications in computer systems. Most computers have only a single processor, so only one user at a time can be serviced. Entries for the other users are placed in a queue. The entry at the front of the queue is the next to receive service. Each entry gradually advances to the front of the queue as users receive service.
- Queues are also used to support print spooling. A multiuser environment might have only a single printer. Many users may be generating outputs to be printed. If the printer is busy, other outputs may still be generated. These are "spooled" to disk (much as thread is wound onto a spool) where they wait in a queue until the printer becomes available.
- Information packets also wait in queues in computer networks. Each time a packet arrives at a network node, it must be routed to the next node on the network along the path to the packet's final

destination. The routing node routes one packet at a time, so additional packets are enqueued until the router can route them.

- A file server in a computer network handles file-access requests from many clients throughout the network. Servers have a limited capacity to service requests from clients. When that capacity is exceeded, client requests wait in queues.
- A tree is a nonlinear, two-dimensional data structure.
- Tree nodes contain two or more links.
- A binary tree is a tree whose nodes all contain two links. The root node is the first node in a tree.
- Each link in the root node refers to a child. The left child is the first node in the left subtree, and the right child is the first node in the right subtree.
- The children of a node are called siblings. A node with no children is called a leaf node.
- Computer scientists normally draw trees from the root node down.
- A binary search tree (with no duplicate node values) has the characteristic that the values in any left subtree are less than the value in its parent node, and the values in any right subtree are greater than the value in its parent node.
- A node can be inserted only as a leaf node in a binary search tree.
- An inorder traversal of a binary search tree processes the node values in ascending order.
- The process of creating a binary search tree actually sorts the data—and thus this process is called the binary tree sort.
- In a preorder traversal, the value in each node is processed as the node is visited. After the value in a given node is processed, the values in the left subtree are processed, then the values in the right subtree are processed.
- In a postorder traversal, the value in each node is processed after the values of its children.
- The binary search tree facilitates duplicate elimination. As the tree is created, attempts to insert a duplicate value are recognized because a duplicate follows the same "go left" or "go right" decisions on each comparison as the original value did. Thus, the duplicate eventually is compared with a node containing the same value. The duplicate value could simply be discarded at this point.
- Searching a binary tree for a value that matches a key value is also fast, especially for tightly packed trees. In a tightly packed tree, each level contains about twice as many elements as the previous level. So a binary search tree with n elements has a minimum of $\log_2 n$ levels, and thus at most $\log_2 n$, comparisons would have to be made either to find a match or to determine that no match exists. Searching a (tightly packed) 1000-element binary search tree requires at most 10 comparisons, because $2^{10} > 1000$. Searching a (tightly packed) 1,000,000-element binary search tree requires at most 20 comparisons, because $2^{20} > 1{,}000{,}000$.

TERMINOLOGY

binary search tree
binary tree
binary tree sort
child node
children
delegating
deleting a node
dequeue
duplicate elimination
dynamic data structures
enqueue
FIFO (first-in, first-out)
head of a queue
inorder traversal of a binary tree
inserting a node
leaf node
left child
left subtree
level-order traversal of a binary tree
LIFO (last-in, first-out)

linear data structure
linked list
node
nonlinear data structure
`null` reference
`OutOfMemoryError`
parent node
pop
postorder traversal of a binary tree
predicate method
preorder traversal of a binary tree
program execution stack
push
queue
recursive tree traversal algorithms
right child
right subtree
root node
self-referential class
stack
subtree
tail of a queue
top of a stack
traversal
tree
visiting a node

SELF-REVIEW EXERCISES

19.1 Fill in the blanks in each of the following statements:

a) A self-_____ class is used to form dynamic data structures that can grow and shrink at execution time.
b) Operator _____ dynamically allocates memory; this operator returns a reference to the allocated memory.
c) A _____ is a constrained version of a linked list in which nodes can be inserted and deleted only from the start of the list; this data structure returns node values in last-in, first-out order.
d) A method that does not alter a linked list, but simply looks at the list to determine whether it is empty is referred to as a _____ method.
e) A queue is referred to as a _____ data structure because the first nodes inserted are the first nodes removed.
f) The reference to the next node in a linked list is referred to as a _____.
g) Automatically reclaiming dynamically allocated memory in Java is called _____.
h) A _____ is a constrained version of a linked list in which nodes can be inserted only at the end of the list and deleted only from the start of the list.
i) A _____ is a nonlinear, two-dimensional data structure that contains nodes with two or more links.
j) A stack is referred to as a _____ data structure because the last node inserted is the first node removed.
k) The nodes of a _____ tree contain two link members.
l) The first node of a tree is the _____ node.
m) Each link in a tree node refers to a _____ or _____ of that node.
n) A tree node that has no children is called a _____ node.
o) The four traversal algorithms we mentioned in the text for binary search trees are _____, _____, _____ and _____.

19.2 What are the differences between a linked list and a stack?

19.3 What are the differences between a stack and a queue?

19.4 Perhaps a more appropriate title for this chapter would have been "Reusable Data Structures." Comment on how each of the following entities or concepts contributes to the reusability of data structures:

a) classes
b) inheritance
c) composition

19.5 Manually provide the inorder, preorder and postorder traversals of the binary search tree of Fig. 19.20.

ANSWERS TO SELF-REVIEW EXERCISES

19.1 a) referential. b) **new**. c) stack. d) predicate. e) first-in, first-out (FIFO). f) link. g) garbage collection. h) queue. i) tree j) last-in, first-out (LIFO). k) binary. l) root. m) child or subtree. n) leaf. o) inorder, preorder, postorder, level order.

19.2 It is possible to insert a node anywhere in a linked list and remove a node from anywhere in a linked list. Nodes in a stack may only be inserted at the top of the stack and removed from the top of a stack.

19.3 A queue is a FIFO data structure that has references to both its head and its tail so that nodes may be inserted at the tail and deleted from the head. A stack is a LIFO data structure that has a single reference to the top of the stack where both insertion and deletion of nodes are performed.

19.4
a) Classes allow us to instantiate as many data structure objects of a certain type (i.e., class) as we wish.
b) Inheritance enables us to reuse code from a superclass in a subclass so that the derived class data structure is also a base-class data structure.
c) Composition enables us to reuse code by making a class object data structure a member of a composed class; if we make the class object a **private** member of the composed class, then the class object's public methods are not available through the composed object's interface.

19.5 The inorder traversal is

```
11 18 19 28 32 40 44 49 69 71 72 83 92 97 99
```

The preorder traversal is

```
49 28 18 11 19 40 32 44 83 71 69 72 97 92 99
```

The postorder traversal is

```
11 19 18 32 44 40 28 69 72 71 92 99 97 83 49
```

EXERCISES

19.6 Write a program that concatenates two linked-list objects of characters. Class **ListConcatenate** should include a method **concatenate** that takes references to both list objects as arguments and concatenates the second list to the first list.

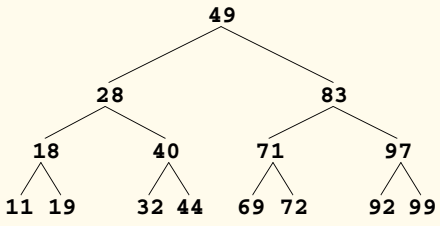


Fig. 19.20 A 15-node binary search tree.

19.7 Write a program that merges two ordered-list objects of integers into a single ordered list object of integers. Method **`merge`** of class **`ListMerge`** should receive references to each of the list objects to be merged and should return a reference to the merged list object.

19.8 Write a program that inserts 25 random integers from 0 to 100 in order into a linked list object. The program should calculate the sum of the elements and the floating-point average of the elements.

19.9 Write a program that creates a linked list object of 10 characters, then creates a second list object containing a copy of the first list, but in reverse order.

19.10 Write a program that inputs a line of text and uses a stack object to print the words of the line in reverse order.

19.11 Write a program that uses a stack to determine whether a string is a palindrome (i.e., the string is spelled identically backward and forward). The program should ignore spaces and punctuation.

19.12 Stacks are used by compilers to help in the process of evaluating expressions and generating machine language code. In this and the next exercise, we investigate how compilers evaluate arithmetic expressions consisting only of constants, operators and parentheses.

Humans generally write expressions like **`3 + 4`** and **`7 / 9`** in which the operator (**`+`** or **`/`** here) is written between its operands—this is called *infix notation*. Computers "prefer" *postfix notation*, in which the operator is written to the right of its two operands. The preceding infix expressions would appear in postfix notation as **`3 4 +`** and **`7 9 /`**, respectively.

To evaluate a complex infix expression, a compiler would first convert the expression to postfix notation and evaluate the postfix version of the expression. Each of these algorithms requires only a single left-to-right pass of the expression. Each algorithm uses a stack object in support of its operation, and in each algorithm, the stack is used for a different purpose.

In this exercise, you will write a Java version of the infix-to-postfix conversion algorithm. In the next exercise, you will write a Java version of the postfix expression evaluation algorithm. In a later exercise, you will discover that code you write in this exercise can help you implement a complete working compiler.

Write class **`InfixToPostfixConverter`** to convert an ordinary infix arithmetic expression (assume a valid expression is entered) with single-digit integers such as

```
(6 + 2) * 5 - 8 / 4
```

to a postfix expression. The postfix version of the preceding infix expression is (note that no parenthesis are needed)

```
6 2 + 5 * 8 4 / -
```

The program should read the expression into **`StringBuffer infix`** and use one of the stack classes implemented in this chapter to help create the postfix expression in **`StringBuffer postfix`**. The algorithm for creating a postfix expression is as follows:

a) Push a left parenthesis **`'('`** on the stack.
b) Append a right parenthesis **`')'`** to the end of **`infix`**.
c) While the stack is not empty, read **`infix`** from left to right and do the following:
   If the current character in **`infix`** is a digit, append it to **`postfix`**.
   If the current character in **`infix`** is a left parenthesis, push it onto the stack.
   If the current character in **`infix`** is an operator:
      Pop operators (if there are any) at the top of the stack while they have equal or higher precedence than the current operator, and append the popped operators to **`postfix`**.
      Push the current character in **`infix`** onto the stack.

If the current character in **infix** is a right parenthesis:
Pop operators from the top of the stack and append them to **postfix** until a left parenthesis is at the top of the stack.
Pop (and discard) the left parenthesis from the stack.

The following arithmetic operations are allowed in an expression:

- **+** addition
- **-** subtraction
- ***** multiplication
- **/** division
- **^** exponentiation
- **%** modulus

The stack should be maintained with stack nodes that each contain an instance variable and a reference to the next stack node. Some of the methods you may want to provide are as follows:

a) Method **convertToPostfix**, which converts the infix expression to postfix notation.
b) Method **isOperator**, which determines whether **c** is an operator.
c) Method **precedence**, which determines if the precedence of **operator1** (from the infix expression) is less than, equal to or greater than the precedence of **operator2** (from the stack). The method returns **true** if **operator1** has lower precedence than **operator2**. Otherwise, **false** is returned.
d) Method **stackTop** (this should be added to the stack class), which returns the top value of the stack without popping the stack.

19.13 Write class **PostfixEvaluator**, which evaluates a postfix expression (assume it is valid) such as

```
6 2 + 5 * 8 4 / -
```

The program should read a postfix expression consisting of digits and operators into a **StringBuffer**. Using modified versions of the stack methods implemented earlier in this chapter, the program should scan the expression and evaluate it. The algorithm is as follows:

a) Append a right parenthesis (**')'**) to the end of the postfix expression. When the right-parenthesis character is encountered, no further processing is necessary.
b) When the right-parenthesis character has not been encountered, read the expression from left to right.
If the current character is a digit do the following:
Push its integer value on the stack (the integer value of a digit character is its value in the computer's character set minus the value of **'0'** in Unicode).
Otherwise, if the current character is an *operator*:
Pop the two top elements of the stack into variables **x** and **y**.
Calculate **y** *operator* **x**.
Push the result of the calculation onto the stack.
c) When the right parenthesis is encountered in the expression, pop the top value of the stack. This is the result of the postfix expression.

[*Note*: In b) above (based on the sample expression at the beginning of this exercises), if the operator is **'/'**, the top of the stack is **2** and the next element in the stack is **8**, then pop **2** into **x**, pop **8** into **y**, evaluate **8 / 2** and push the result, **4**, back on the stack. This note also applies to operator **'-'**.]
The arithmetic operations allowed in an expression are:

- **+** addition
- **-** subtraction
- ***** multiplication
- **/** division

^ exponentiation
% modulus

The stack should be maintained with one of the stack classes introduced in this chapter. You may want to provide the following methods:

a) Method **evaluatePostfixExpression**, which evaluates the postfix expression.
b) Method **calculate**, which evaluates the expression **op1 operator op2**.
c) Method **push**, which pushes a value onto the stack.
d) Method **pop**, which pops a value off the stack.
e) Method **isEmpty**, which determines whether the stack is empty.
f) Method **printStack**, which prints the stack.

19.14 Modify the postfix evaluator program of Exercise 19.13 so that it can process integer operands larger than 9.

19.15 *(Supermarket Simulation)* Write a program that simulates a checkout line at a supermarket. The line is a queue object. Customers (i.e., customer objects) arrive in random integer intervals of from 1 to 4 minutes. Also, each customer is serviced in random integer intervals of from 1 to 4 minutes. Obviously, the rates need to be balanced. If the average arrival rate is larger than the average service rate, the queue will grow infinitely. Even with "balanced" rates, randomness can still cause long lines. Run the supermarket simulation for a 12-hour day (720 minutes), using the following algorithm:

a) Choose a random integer between 1 and 4 to determine the minute at which the first customer arrives.
b) At the first customer's arrival time, do the following:
   Determine customer's service time (random integer from 1 to 4).
   Begin servicing the customer.
   Schedule the arrival time of the next customer (random integer 1 to 4 added to the current time).
c) For each minute of the day, consider the following:
   If the next customer arrives, proceed as follows:
      Say so.
      Enqueue the customer.
      Schedule the arrival time of the next customer.
   If service was completed for the last customer, do the following:
      Say so.
      Dequeue next customer to be serviced.
      Determine customer's service completion time (random integer from 1 to 4 added to the current time).

Now run your simulation for 720 minutes and answer each of the following:

a) What is the maximum number of customers in the queue at any time?
b) What is the longest wait any one customer experiences?
c) What happens if the arrival interval is changed from 1 to 4 minutes to 1 to 3 minutes?

19.16 Modify the program of Fig. 19.17 and Fig. 19.18 to allow the binary tree to contain duplicates.

19.17 Write a program based on the program of Fig. 19.17 and Fig. 19.18 that inputs a line of text, tokenizes the sentence into separate words (you might want to use the **StreamTokenizer** class from the **java.io** package), inserts the words in a binary search tree and prints the inorder, preorder and post-order traversals of the tree.

19.18 In this chapter, we saw that duplicate elimination is straightforward when creating a binary search tree. Describe how you would perform duplicate elimination when using only a single-subscripted array. Compare the performance of array-based duplicate elimination with the performance of binary-search-tree-based duplicate elimination.

19.19 Write a method **depth** that receives a binary tree and determines how many levels it has.

19.20 (*Recursively Print a List Backwards*) Write a method **printListBackwards** that recursively outputs the items in a linked list object in reverse order. Write a test program that creates a sorted list of integers and prints the list in reverse order.

19.21 (*Recursively Search a List*) Write a method **searchList** that recursively searches a linked list object for a specified value. Method **searchList** should return a reference to the value if it is found; otherwise, null should be returned. Use your method in a test program that creates a list of integers. The program should prompt the user for a value to locate in the list.

19.22 (*Binary Tree Delete*) In this exercise, we discuss deleting items from binary search trees. The deletion algorithm is not as straightforward as the insertion algorithm. There are three cases that are encountered when deleting an item—the item is contained in a leaf node (i.e., it has no children), the item is contained in a node that has one child or the item is contained in a node that has two children.

If the item to be deleted is contained in a leaf node, the node is deleted and the reference in the parent node is set to null.

If the item to be deleted is contained in a node with one child, the reference in the parent node is set to reference the child node and the node containing the data item is deleted. This causes the child node to take the place of the deleted node in the tree.

The last case is the most difficult. When a node with two children is deleted, another node in the tree must take its place. However, the reference in the parent node cannot simply be assigned to reference one of the children of the node to be deleted. In most cases, the resulting binary search tree would not adhere to the following characteristic of binary search trees (with no duplicate values): *The values in any left subtree are less than the value in the parent node, and the values in any right subtree are greater than the value in the parent node.*

Which node is used as a *replacement node* to maintain this characteristic? It is either the node containing the largest value in the tree less than the value in the node being deleted, or the node containing the smallest value in the tree greater than the value in the node being deleted. Let us consider the node with the smaller value. In a binary search tree, the largest value less than a parent's value is located in the left subtree of the parent node and is guaranteed to be contained in the rightmost node of the subtree. This node is located by walking down the left subtree to the right until the reference to the right child of the current node is null. We are now referencing the replacement node, which is either a leaf node or a node with one child to its left. If the replacement node is a leaf node, the steps to perform the deletion are as follows:

a) Store the reference to the node to be deleted in a temporary reference variable.
b) Set the reference in the parent of the node being deleted to reference the replacement node.
c) Set the reference in the parent of the replacement node to null.
d) Set the reference to the right subtree in the replacement node to reference the right subtree of the node to be deleted.
e) Set the reference to the left subtree in the replacement node to reference the left subtree of the node to be deleted.

The deletion steps for a replacement node with a left child are similar to those for a replacement node with no children, but the algorithm also must move the child into the replacement node's position in the tree. If the replacement node is a node with a left child, the steps to perform the deletion are as follows:

a) Store the reference to the node to be deleted in a temporary reference variable.
b) Set the reference in the parent of the node being deleted to reference the replacement node.
c) Set the reference in the parent of the replacement node reference to the left child of the replacement node.

d) Set the reference to the right subtree in the replacement node reference to the right subtree of the node to be deleted.
e) Set the reference to the left subtree in the replacement node to reference the left subtree of the node to be deleted.

Write method **`deleteNode`**, which takes as its argument the value to be deleted. Method **`deleteNode`** should locate in the tree the node containing the value to be deleted and use the algorithms discussed here to delete the node. If the value is not found in the tree, the method should print a message that indicates whether the value is deleted. Modify the program of Fig. 19.17 and Fig. 19.18 to use this method. After deleting an item, call the methods **`inorderTraversal`**, **`preorderTraversal`** and **`postorderTraversal`** to confirm that the delete operation was performed correctly.

19.23 (*Binary Tree Search*) Write method **`binaryTreeSearch`**, which attempts to locate a specified value in a binary search tree object. The method should take as an argument a search key to be located. If the node containing the search key is found, the method should return a reference to that node; otherwise, the method should return a null reference.

19.24 (*Level-Order Binary Tree Traversal*) The program of Fig. 19.17 and Fig. 19.18 illustrated three recursive methods of traversing a binary tree—inorder, preorder and postorder traversals. This exercise presents the *level-order traversal* of a binary tree, in which the node values are printed level-by-level, starting at the root node level. The nodes on each level are printed from left to right. The level-order traversal is not a recursive algorithm. It uses a queue object to control the output of the nodes. The algorithm is as follows:

a) Insert the root node in the queue.
b) While there are nodes left in the queue, do the following:
    Get the next node in the queue.
    Print the node's value.
    If the reference to the left child of the node is not null:
        Insert the left child node in the queue.
    If the reference to the right child of the node is not null:
        Insert the right child node in the queue.

Write method **`levelOrder`** to perform a level-order traversal of a binary tree object. Modify the program of Fig. 19.17 and Fig. 19.18 to use this method. [*Note*: You will also need to use queue-processing methods of Fig. 19.13 in this program.]

19.25 (*Printing Trees*) Write a recursive method **`outputTree`** to display a binary tree object on the screen. The method should output the tree row-by-row, with the top of the tree at the left of the screen and the bottom of the tree toward the right of the screen. Each row is output vertically. For example, the binary tree illustrated in Fig. 19.20 is output as shown in Fig. 19.21.

Note that the rightmost leaf node appears at the top of the output in the rightmost column and the root node appears at the left of the output. Each column of output starts five spaces to the right of the preceding column. Method **`outputTree`** should receive an argument **`totalSpaces`** representing the number of spaces preceding the value to be output. (This variable should start at zero so the root node is output at the left of the screen.) The method uses a modified inorder traversal to output the tree—it starts at the rightmost node in the tree and works back to the left. The algorithm is as follows:

While the reference to the current node is not null, perform the following:
    Recursively call **`outputTree`** with the right subtree of the current node and
        `totalSpaces + 5`.
    Use a **`for`** structure to count from 1 to **`totalSpaces`** and output spaces.
    Output the value in the current node.
    Set the reference to the current node to refer to the left subtree of the current node.
    Increment **`totalSpaces`** by 5.

```
                99
          97
                92
     83
                72
          71
                69
49
                44
          40
                32
     28
                19
          18
                11
```

Fig. 19.21 Sample output of recursive method **outputTree**.

SPECIAL SECTION: BUILDING YOUR OWN COMPILER

In Exercise 7.42 and Exercise 7.43, we introduced Simpletron Machine Language (SML), and you implemented a Simpletron computer simulator to execute programs written in SML. In this section, we build a compiler that converts programs written in a high-level programming language to SML. This section "ties" together the entire programming process. You will write programs in this new high-level language, compile these programs on the compiler you build and run the programs on the simulator you built in Exercise 7.43. You should make every effort to implement your compiler in an object-oriented manner.

19.26 (*The Simple Language*) Before we begin building the compiler, we discuss a simple, yet powerful high-level language similar to early versions of the popular language Basic. We call the language *Simple*. Every Simple *statement* consists of a *line number* and a Simple *instruction*. Line numbers must appear in ascending order. Each instruction begins with one of the following Simple *commands*: **rem**, **input**, **let**, **print**, **goto**, **if/goto** or **end** (see Fig. 19.22). All commands except **end** can be used repeatedly. Simple evaluates only integer expressions using the **+**, **-**, ***** and **/** operators. These operators have the same precedence as in Java. Parentheses can be used to change the order of evaluation of an expression.

Command	Example statement	Description
rem	`50 rem this is a remark`	Any text following the command **rem** is for documentation purposes only and is ignored by the compiler.
input	`30 input x`	Display a question mark to prompt the user to enter an integer. Read that integer from the keyboard and store the integer in **x**.
let	`80 let u = 4 * (j - 56)`	Assign **u** the value of **4 * (j - 56)**. Note that an arbitrarily complex expression can appear to the right of the equal sign.

Fig. 19.22 Simple commands (part 1 of 2).

Command	Example statement	Description
`print`	`10 print w`	Display the value of **w**.
`goto`	`70 goto 45`	Transfer program control to line **45**.
`if/goto`	`35 if i == z goto 80`	Compare **i** and **z** for equality and transfer program control to line **80** if the condition is true; otherwise, continue execution with the next statement.
`end`	`99 end`	Terminate program execution.

Fig. 19.22 Simple commands (part 2 of 2).

Our Simple compiler recognizes only lowercase letters. All characters in a Simple file should be lowercase. (Uppercase letters result in a syntax error unless they appear in a **rem** statement, in which case they are ignored.) A *variable name* is a single letter. Simple does not allow descriptive variable names, so variables should be explained in remarks to indicate their use in a program. Simple uses only integer variables. Simple does not have variable declarations—merely mentioning a variable name in a program causes the variable to be declared and initialized to zero. The syntax of Simple does not allow string manipulation (reading a string, writing a string, comparing strings etc.). If a string is encountered in a Simple program (after a command other than **rem**), the compiler generates a syntax error. The first version of our compiler assumes that Simple programs are entered correctly. Exercise 19.29 asks the reader to modify the compiler to perform syntax error checking.

Simple uses the conditional **if/goto** and unconditional **goto** statements to alter the flow of control during program execution. If the condition in the **if/goto** statement is true, control is transferred to a specific line of the program. The following relational and equality operators are valid in an **if/goto** statement: **<**, **>**, **<=**, **>=**, **==** or **!=**. The precedence of these operators is the same as in Java.

Let us now consider several programs that demonstrate Simple's features. The first program (Fig. 19.23) reads two integers from the keyboard, stores the values in variables **a** and **b** and computes and prints their sum (stored in variable **c**).

The program of Fig. 19.24 determines and prints the larger of two integers. The integers are input from the keyboard and stored in **s** and **t**. The **if/goto** statement tests the condition **s >= t**. If the condition is true, control is transferred to line **90** and **s** is output; otherwise, **t** is output and control is transferred to the **end** statement in line **99**, where the program terminates.

```
1   10 rem   determine and print the sum of two integers
2   15 rem
3   20 rem   input the two integers
4   30 input a
5   40 input b
6   45 rem
7   50 rem   add integers and store result in c
8   60 let c = a + b
9   65 rem
10  70 rem   print the result
11  80 print c
12  90 rem   terminate program execution
13  99 end
```

Fig. 19.23 Simple program that determines the sum of two integers.

Simple does not provide a repetition structure (such as Java's **for**, **while** or **do/while**). However, Simple can simulate each of Java's repetition structures by using the **if/goto** and **goto** statements. Figure 19.25 uses a sentinel-controlled loop to calculate the squares of several integers. Each integer is input from the keyboard and stored in variable **j**. If the value entered is the sentinel value **-9999**, control is transferred to line **99**, where the program terminates. Otherwise, **k** is assigned the square of **j**, **k** is output to the screen and control is passed to line **20**, where the next integer is input.

Using the sample programs of Fig. 19.23–Fig. 19.25 as your guide, write a Simple program to accomplish each of the following:

a) Input three integers, determine their average and print the result.
b) Use a sentinel-controlled loop to input 10 integers and compute and print their sum.
c) Use a counter-controlled loop to input 7 integers, some positive and some negative, and compute and print their average.
d) Input a series of integers and determine and print the largest. The first integer input indicates how many numbers should be processed.
e) Input 10 integers and print the smallest.
f) Calculate and print the sum of the even integers from 2 to 30.
g) Calculate and print the product of the odd integers from 1 to 9.

```
1  10 rem   determine and print the larger of two integers
2  20 input s
3  30 input t
4  32 rem
5  35 rem   test if s >= t
6  40 if s >= t goto 90
7  45 rem
8  50 rem   t is greater than s, so print t
9  60 print t
10 70 goto 99
11 75 rem
12 80 rem   s is greater than or equal to t, so print s
13 90 print s
14 99 end
```

Fig. 19.24 Simple program that finds the larger of two integers.

```
1  10 rem   calculate the squares of several integers
2  20 input j
3  23 rem
4  25 rem   test for sentinel value
5  30 if j == -9999 goto 99
6  33 rem
7  35 rem   calculate square of j and assign result to k
8  40 let k = j * j
9  50 print k
10 53 rem
11 55 rem   loop to get next j
12 60 goto 20
13 99 end
```

Fig. 19.25 Calculate the squares of several integers.

19.27 (*Building A Compiler; Prerequisite: Complete Exercise 7.42, Exercise 7.43, Exercise 19.12, Exercise 19.13 and Exercise 19.26*) Now that the Simple language has been presented (Exercise 19.26), we discuss how to build a Simple compiler. First, we consider the process by which a Simple program is converted to SML and executed by the Simpletron simulator (see Fig. 19.26). A file containing a Simple program is read by the compiler and converted to SML code. The SML code is output to a file on disk, in which SML instructions appear one per line. The SML file is then loaded into the Simpletron simulator, and the results are sent to a file on disk and to the screen. Note that the Simpletron program developed in Exercise 7.43 took its input from the keyboard. It must be modified to read from a file so it can run the programs produced by our compiler.

The Simple compiler performs two *passes* of the Simple program to convert it to SML. The first pass constructs a *symbol table* (object) in which every *line number* (object), *variable name* (object) and *constant* (object) of the Simple program is stored with its type and corresponding location in the final SML code (the symbol table is discussed in detail below). The first pass also produces the corresponding SML instruction object(s) for each of the Simple statements (object, etc.). If the Simple program contains statements that transfer control to a line later in the program, the first pass results in an SML program containing some "unfinished" instructions. The second pass of the compiler locates and completes the unfinished instructions and outputs the SML program to a file.

First Pass

The compiler begins by reading one statement of the Simple program into memory. The line must be separated into its individual *tokens* (i.e., "pieces" of a statement) for processing and compilation. (The **`StreamTokenizer`** class from the **`java.io`** package can be used.) Recall that every statement begins with a line number followed by a command. As the compiler breaks a statement into tokens, if the token is a line number, a variable or a constant, it is placed in the symbol table. A line number is placed in the symbol table only if it is the first token in a statement. The **`symbolTable`** object is an array of **`tableEntry`** objects representing each symbol in the program. There is no restriction on the number of symbols that can appear in the program. Therefore, the **`symbolTable`** for a particular program could be large. Make the **`symbolTable`** a 100-element array for now. You can increase or decrease its size once the program is working.

Each **`tableEntry`** object contains three members. Member **`symbol`** is an integer containing the Unicode representation of a variable (remember that variable names are single characters), a line number or a constant. Member **`type`** is one of the following characters indicating the symbol's type: **`'C'`** for constant, **`'L'`** for line number or **`'V'`** for variable. Member **`location`** contains the Simpletron memory location (**`00`** to **`99`**) to which the symbol refers. Simpletron memory is an array of 100 integers in which SML instructions and data are stored. For a line number, the location is the element in the Simpletron memory array at which the SML instructions for the Simple statement begin. For a variable or constant, the location is the element in the Simpletron memory array in which the variable or constant is stored. Variables and constants are allocated from the end of Simpletron's memory backwards. The first variable or constant is stored at location **`99`**, the next at location **`98`**, etc.

The symbol table plays an integral part in converting Simple programs to SML. We learned in Chapter 7 that an SML instruction is a four-digit integer comprised of two parts—the *operation code* and the *operand*. The operation code is determined by commands in Simple. For example, the simple command **`input`** corresponds to SML operation code **`10`** (read), and the Simple command **`print`** corresponds to SML operation code **`11`** (write). The operand is a memory location containing the data on which the operation code performs its task (e.g., operation code **`10`** reads a value from the keyboard and stores it in the memory location specified by the operand). The compiler searches **`symbolTable`** to determine the Simpletron memory location for each symbol, so the corresponding location can be used to complete the SML instructions.

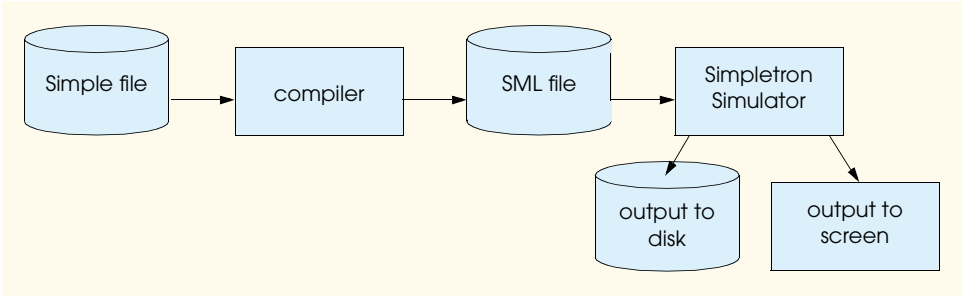


Fig. 19.26 Writing, compiling and executing a Simple language program.

The compilation of each Simple statement is based on its command. For example, after the line number in a **`rem`** statement is inserted in the symbol table, the remainder of the statement is ignored by the compiler because a remark is for documentation purposes only. The **`input`**, **`print`**, **`goto`** and **`end`** statements correspond to the SML *read, write, branch (*to a specific location) and *halt* instructions. Statements containing these Simple commands are converted directly to SML. (*Note*: A **`goto`** statement may contain an unresolved reference if the specified line number refers to a statement further into the Simple program file; this is sometimes called a forward reference.)

When a **`goto`** statement is compiled with an unresolved reference, the SML instruction must be *flagged* to indicate that the second pass of the compiler must complete the instruction. The flags are stored in a 100-element array **`flags`** of type **`int`** in which each element is initialized to **`-1`**. If the memory location to which a line number in the Simple program refers is not yet known (i.e., it is not in the symbol table), the line number is stored in array **`flags`** in the element with the same subscript as the incomplete instruction. The operand of the incomplete instruction is set to **`00`** temporarily. For example, an unconditional branch instruction (making a forward reference) is left as **`+4000`** until the second pass of the compiler. The second pass of the compiler will be described shortly.

Compilation of **`if/goto`** and **`let`** statements is more complicated than other statements—they are the only statements that produce more than one SML instruction. For an **`if/goto`** statement, the compiler produces code to test the condition and to branch to another line if necessary. The result of the branch could be an unresolved reference. Each of the relational and equality operators can be simulated by using SML's *branch zero* and *branch negative* instructions (or possibly a combination of both).

For a **`let`** statement, the compiler produces code to evaluate an arbitrarily complex arithmetic expression consisting of integer variables and/or constants. Expressions should separate each operand and operator with spaces. Exercise 19.12 and Exercise 19.13 presented the infix-to-postfix conversion algorithm and the postfix evaluation algorithm used by compilers to evaluate expressions. Before proceeding with your compiler, you should complete each of these exercises. When a compiler encounters an expression, it converts the expression from infix notation to postfix notation, then evaluates the postfix expression.

How is it that the compiler produces the machine language to evaluate an expression containing variables? The postfix evaluation algorithm contains a "hook" where the compiler can generate SML instructions rather than actually evaluating the expression. To enable this "hook" in the compiler, the postfix evaluation algorithm must be modified to search the symbol table for each symbol it encounters (and possibly insert it), determine the symbol's corresponding memory location and *push the memory location on the stack (instead of the symbol).* When an operator is encountered in the postfix expression, the two memory locations at the top of the stack are popped, and machine language for effecting the operation is produced by using the memory locations as operands. The result of each subexpression is stored in a temporary location in memory and pushed back onto the stack so the

evaluation of the postfix expression can continue. When postfix evaluation is complete, the memory location containing the result is the only location left on the stack. This is popped, and SML instructions are generated to assign the result to the variable at the left of the **let** statement.

Second Pass

The second pass of the compiler performs two tasks: Resolve any unresolved references and output the SML code to a file. Resolution of references occurs as follows:

a) Search the **flags** array for an unresolved reference (i.e., an element with a value other than **-1**).
b) Locate the object in array **symbolTable** containing the symbol stored in the **flags** array (be sure that the type of the symbol is **'L'** for line number).
c) Insert the memory location from member **location** into the instruction with the unresolved reference (remember that an instruction containing an unresolved reference has operand **00**).
d) Repeat steps (a), (b) and (c) until the end of the **flags** array is reached.

After the resolution process is complete, the entire array containing the SML code is output to a disk file with one SML instruction per line. This file can be read by the Simpletron for execution (after the simulator is modified to read its input from a file). Compiling your first Simple program into an SML file and executing that file should give you a real sense of personal accomplishment.

A Complete Example

The following example illustrates complete conversion of a Simple program to SML as it will be performed by the Simple compiler. Consider a Simple program that inputs an integer and sums the values from 1 to that integer. The program and the SML instructions produced by the first pass of the Simple compiler are illustrated in Fig. 19.27. The symbol table constructed by the first pass is shown in Fig. 19.28. .

Simple program	SML location and instruction	Description
`5 rem sum 1 to x`	*none*	**rem** ignored
`10 input x`	`00 +1099`	read **x** into location **99**
`15 rem check y == x`	*none*	**rem** ignored
`20 if y == x goto 60`	`01 +2098`	load **y** (**98**) into accumulator
	`02 +3199`	sub **x** (**99**) from accumulator
	`03 +4200`	branch zero to unresolved location
`25 rem increment y`	*none*	**rem** ignored
`30 let y = y + 1`	`04 +2098`	load **y** into accumulator
	`05 +3097`	add **1** (**97**) to accumulator
	`06 +2196`	store in temporary location **96**
	`07 +2096`	load from temporary location **96**
	`08 +2198`	store accumulator in **y**
`35 rem add y to total`	*none*	**rem** ignored

Fig. 19.27 SML instructions produced after the compiler's first pass (part 1 of 2).

Simple program	SML location and instruction	Description
`40 let t = t + y`	`09 +2095`	load **t** (**95**) into accumulator
	`10 +3098`	add **y** to accumulator
	`11 +2194`	store in temporary location **94**
	`12 +2094`	load from temporary location **94**
	`13 +2195`	store accumulator in **t**
`45 rem loop y`	*none*	**rem** ignored
`50 goto 20`	`14 +4001`	branch to location **01**
`55 rem output result`	*none*	**rem** ignored
`60 print t`	`15 +1195`	output **t** to screen
`99 end`	`16 +4300`	terminate execution

Fig. 19.27 SML instructions produced after the compiler's first pass (part 2 of 2).

Symbol	Type	Location
`5`	`L`	`00`
`10`	`L`	`00`
`'x'`	`V`	`99`
`15`	`L`	`01`
`20`	`L`	`01`
`'y'`	`V`	`98`
`25`	`L`	`04`
`30`	`L`	`04`
`1`	`C`	`97`
`35`	`L`	`09`
`40`	`L`	`09`
`'t'`	`V`	`95`
`45`	`L`	`14`
`50`	`L`	`14`
`55`	`L`	`15`
`60`	`L`	`15`
`99`	`L`	`16`

Fig. 19.28 Symbol table for program of Fig. 19.27.

Most Simple statements convert directly to single SML instructions. The exceptions in this program are remarks, the **if/goto** statement in line **20** and the **let** statements. Remarks do not translate into machine language. However, the line number for a remark is placed in the symbol table in

case the line number is referenced in a **goto** statement or an **if/goto** statement. Line **20** of the program specifies that, if the condition **y == x** is true, program control is transferred to line **60**. Since line **60** appears later in the program, the first pass of the compiler has not as yet placed **60** in the symbol table. (Statement line numbers are placed in the symbol table only when they appear as the first token in a statement.) Therefore, it is not possible at this time to determine the operand of the SML *branch zero* instruction at location **03** in the array of SML instructions. The compiler places **60** in location **03** of the **flags** array to indicate that the second pass completes this instruction.

We must keep track of the next instruction location in the SML array because there is not a one-to-one correspondence between Simple statements and SML instructions. For example, the **if/goto** statement of line **20** compiles into three SML instructions. Each time an instruction is produced, we must increment the *instruction counter* to the next location in the SML array. Note that the size of Simpletron's memory could present a problem for Simple programs with many statements, variables and constants. It is conceivable that the compiler will run out of memory. To test for this case, your program should contain a *data counter* to keep track of the location at which the next variable or constant will be stored in the SML array. If the value of the instruction counter is larger than the value of the data counter, the SML array is full. In this case, the compilation process should terminate, and the compiler should print an error message indicating that it ran out of memory during compilation. This serves to emphasize that, although the programmer is freed from the burdens of managing memory by the compiler, the compiler itself must carefully determine the placement of instructions and data in memory and must check for such errors as memory being exhausted during the compilation process.

A Step-by-Step View of the Compilation Process

Let us now walk through the compilation process for the Simple program in Fig. 19.27. The compiler reads the first line of the program

```
5 rem sum 1 to x
```

into memory. The first token in the statement (the line number) is determined using the **StreamTokenizer** class (see Chapter 10 for a discussion of Java's string manipulation methods). The token returned by the **StreamTokenizer** is converted to an integer by using **static** method **Integer.parseInt()**, so the symbol **5** can be located in the symbol table. If the symbol is not found, it is inserted in the symbol table.

We are at the beginning of the program and this is the first line, and no symbols are in the table yet. Therefore, **5** is inserted into the symbol table as type **L** (line number) and assigned the first location in SML array (**00**). Although this line is a remark, a space in the symbol table is still allocated for the line number (in case it is referenced by a **goto** or an **if/goto**). No SML instruction is generated for a **rem** statement, so the instruction counter is not incremented.

```
10 input x
```

is tokenized next. The line number **10** is placed in the symbol table as type **L** and assigned the first location in the SML array (**00** because a remark began the program, so the instruction counter is currently **00**). The command **input** indicates that the next token is a variable (only a variable can appear in an **input** statement). **input** corresponds directly to an SML operation code; therefore, the compiler simply has to determine the location of **x** in the SML array. Symbol **x** is not found in the symbol table. So, it is inserted into the symbol table as the Unicode representation of **x**, given type **V** and assigned location **99** in the SML array (data storage begins at **99** and is allocated backwards). SML code can now be generated for this statement. Operation code **10** (the SML read operation code) is multiplied by 100, and the location of **x** (as determined in the symbol table) is added to complete the instruction. The instruction is then stored in the SML array at location **00**. The instruction counter is incremented by one, because a single SML instruction was produced.

The statement

```
15 rem   check y == x
```

is tokenized next. The symbol table is searched for line number **15** (which is not found). The line number is inserted as type **L** and assigned the next location in the array, **01**. (Remember that **rem** statements do not produce code, so the instruction counter is not incremented.)

The statement

```
20 if y == x goto 60
```

is tokenized next. Line number **20** is inserted in the symbol table and given type **L** at the next location in the SML array **01**. The command **if** indicates that a condition is to be evaluated. The variable **y** is not found in the symbol table, so it is inserted and given the type **V** and the SML location **98**. Next, SML instructions are generated to evaluate the condition. There is no direct equivalent in SML for the **if**/**goto**; it must be simulated by performing a calculation using **x** and **y** and branching according to the result. If **y** is equal to **x**, the result of subtracting **x** from **y** is zero, so the *branch zero* instruction can be used with the result of the calculation to simulate the **if**/**goto** statement. The first step requires that **y** be loaded (from SML location **98**) into the accumulator. This produces the instruction **01 +2098**. Next, **x** is subtracted from the accumulator. This produces the instruction **02 +3199**. The value in the accumulator may be zero, positive or negative. The operator is **==**, so we want to *branch zero.* First, the symbol table is searched for the branch location (**60** in this case), which is not found. So, **60** is placed in the **flags** array at location **03**, and the instruction **03 +4200** is generated. (We cannot add the branch location because we have not yet assigned a location to line **60** in the SML array.) The instruction counter is incremented to **04**.

The compiler proceeds to the statement

```
25 rem   increment y
```

The line number **25** is inserted in the symbol table as type **L** and assigned SML location **04**. The instruction counter is not incremented.

When the statement

```
30 let y = y + 1
```

is tokenized, the line number **30** is inserted in the symbol table as type **L** and assigned SML location **04**. Command **let** indicates that the line is an assignment statement. First, all the symbols on the line are inserted in the symbol table (if they are not already there). The integer **1** is added to the symbol table as type **C** and assigned SML location **97**. Next, the right side of the assignment is converted from infix to postfix notation. Then the postfix expression (**y 1 +**) is evaluated. Symbol **y** is located in the symbol table, and its corresponding memory location is pushed onto the stack. Symbol **1** is also located in the symbol table, and its corresponding memory location is pushed onto the stack. When the operator **+** is encountered, the postfix evaluator pops the stack into the right operand of the operator and pops the stack again into the left operand of the operator, then produces the SML instructions

```
04 +2098    (load y)
05 +3097    (add 1)
```

The result of the expression is stored in a temporary location in memory (**96**) with instruction

```
06 +2196    (store temporary)
```

and the temporary location is pushed onto the stack. Now that the expression has been evaluated, the result must be stored in **y** (i.e., the variable on the left side of **=**). So, the temporary location is loaded into the accumulator and the accumulator is stored in **y** with the instructions

```
07 +2096    (load temporary)
08 +2198    (store y)
```

The reader will immediately notice that SML instructions appear to be redundant. We will discuss this issue shortly.

When the statement

```
35 rem   add y to total
```

is tokenized, line number **35** is inserted in the symbol table as type **L** and assigned location **09**.

The statement

```
40 let t = t + y
```

is similar to line **30**. The variable **t** is inserted in the symbol table as type **V** and assigned SML location **95**. The instructions follow the same logic and format as line **30**, and the instructions **09 +2095**, **10 +3098**, **11 +2194**, **12 +2094** and **13 +2195** are generated. Note that the result of **t + y** is assigned to temporary location **94** before being assigned to **t** (**95**). Once again, the reader will note that the instructions in memory locations **11** and **12** appear to be redundant. Again, we will discuss this shortly.

The statement

```
45 rem   loop y
```

is a remark, so line **45** is added to the symbol table as type **L** and assigned SML location **14**.

The statement

```
50 goto 20
```

transfers control to line **20**. Line number **50** is inserted in the symbol table as type **L** and assigned SML location **14**. The equivalent of **goto** in SML is the *unconditional branch* (**40**) instruction that transfers control to a specific SML location. The compiler searches the symbol table for line **20** and finds that it corresponds to SML location **01**. The operation code (**40**) is multiplied by 100, and location **01** is added to it to produce the instruction **14 +4001**.

The statement

```
55 rem   output result
```

is a remark, so line **55** is inserted in the symbol table as type **L** and assigned SML location **15**.

The statement

```
60 print t
```

is an output statement. Line number **60** is inserted in the symbol table as type **L** and assigned SML location **15**. The equivalent of **print** in SML is operation code **11** (*write*). The location of **t** is determined from the symbol table and added to the result of the operation code multiplied by 100.

The statement

```
99 end
```

is the final line of the program. Line number **99** is stored in the symbol table as type **L** and assigned SML location **16**. The **end** command produces the SML instruction **+4300** (**43** is *halt* in SML), which is written as the final instruction in the SML memory array.

This completes the first pass of the compiler. We now consider the second pass. The **flags** array is searched for values other than **-1**. Location **03** contains **60**, so the compiler knows that instruction **03** is incomplete. The compiler completes the instruction by searching the symbol

table for **60**, determining its location and adding the location to the incomplete instruction. In this case, the search determines that line **60** corresponds to SML location **15**, so the completed instruction **03 +4215** is produced, replacing **03 +4200**. The Simple program has now been compiled successfully.

To build the compiler, you will have to perform each of the following tasks:

a) Modify the Simpletron simulator program you wrote in Exercise 7.43 to take its input from a file specified by the user (see Chapter 16). The simulator should output its results to a disk file in the same format as the screen output. Convert the simulator to be an object-oriented program. In particular, make each part of the hardware an object. Arrange the instruction types into a class hierarchy using inheritance. Then execute the program polymorphically simply by telling each instruction to execute itself with an **executeInstruction** message.

b) Modify the infix-to-postfix evaluation algorithm of Exercise 19.12 to process multidigit integer operands and single-letter variable name operands. (*Hint*: Class **StreamTokenizer** can be used to locate each constant and variable in an expression, and constants can be converted from strings to integers by using **Integer** class method **parseInt**.) [*Note*: The data representation of the postfix expression must be altered to support variable names and integer constants.]

c) Modify the postfix evaluation algorithm to process multidigit integer operands and variable name operands. Also, the algorithm should now implement the "hook" discussed earlier so that SML instructions are produced rather than directly evaluating the expression. (*Hint*: Class **StreamTokenizer** can be used to locate each constant and variable in an expression, and constants can be converted from strings to integers by using **Integer** class method **parseInt**.) [*Note*: The data representation of the postfix expression must be altered to support variable names and integer constants.]

d) Build the compiler. Incorporate parts b) and c) for evaluating expressions in **let** statements. Your program should contain a method that performs the first pass of the compiler and a method that performs the second pass of the compiler. Both methods can call other methods to accomplish their tasks. Make your compiler as object oriented as possible.

19.28 (*Optimizing the Simple Compiler*) When a program is compiled and converted into SML, a set of instructions is generated. Certain combinations of instructions often repeat themselves, usually in triplets called *productions*. A production normally consists of three instructions, such as *load*, *add* and *store*. For example, Fig. 19.29 illustrates five of the SML instructions that were produced in the compilation of the program in Fig. 19.27. The first three instructions are the production that adds **1** to **y**. Note that instructions **06** and **07** store the accumulator value in temporary location **96**, then load the value back into the accumulator so instruction **08** can store the value in location **98**. Often a production is followed by a load instruction for the same location that was just stored. This code can be *optimized* by eliminating the store instruction and the subsequent load instruction that operate on the same memory location, thus enabling the Simpletron to execute the program faster. Figure 19.30 illustrates the optimized SML for the program of Fig. 19.27. Note that there are four fewer instructions in the optimized code—a memory-space savings of 25%.

```
1  04  +2098  (load)
2  05  +3097  (add)
3  06  +2196  (store)
4  07  +2096  (load)
5  08  +2198  (store)
```

Fig. 19.29 Unoptimized code from the program of Fig. 19.25.

Simple program	SML location and instruction	Description
`5 rem sum 1 to x`	*none*	**rem** ignored
`10 input x`	`00 +1099`	read **x** into location **99**
`15 rem check y == x`	*none*	**rem** ignored
`20 if y == x goto 60`	`01 +2098`	load **y** (**98**) into accumulator
	`02 +3199`	sub **x** (**99**) from accumulator
	`03 +4211`	branch to location **11** if zero
`25 rem increment y`	*none*	**rem** ignored
`30 let y = y + 1`	`04 +2098`	load **y** into accumulator
	`05 +3097`	add **1** (**97**) to accumulator
	`06 +2198`	store accumulator in **y** (**98**)
`35 rem add y to total`	*none*	**rem** ignored
`40 let t = t + y`	`07 +2096`	load **t** from location (**96**)
	`08 +3098`	add **y** (**98**) accumulator
	`09 +2196`	store accumulator in **t** (**96**)
`45 rem loop y`	*none*	**rem** ignored
`50 goto 20`	`10 +4001`	branch to location **01**
`55 rem output result`	*none*	**rem** ignored
`60 print t`	`11 +1196`	output **t** (**96**) to screen
`99 end`	`12 +4300`	terminate execution

Fig. 19.30 Optimized code for the program of Fig. 19.27.

19.29 (*Modifications to the Simple Compiler*) Perform the following modifications to the Simple compiler. Some of these modifications might also require modifications to the Simpletron simulator program written in Exercise 7.43.

a) Allow the modulus operator (**%**) to be used in **let** statements. Simpletron Machine Language must be modified to include a modulus instruction.

b) Allow exponentiation in a **let** statement using **^** as the exponentiation operator. Simpletron Machine Language must be modified to include an exponentiation instruction.

c) Allow the compiler to recognize uppercase and lowercase letters in Simple statements (e.g., **'A'** is equivalent to **'a'**). No modifications to the Simpletron simulator are required.

d) Allow **input** statements to read values for multiple variables such as **input x, y**. No modifications to the Simpletron simulator are required to perform this enhancement to the Simple compiler.

e) Allow the compiler to output multiple values from a single **print** statement, such as **print a, b, c**. No modifications to the Simpletron simulator are required to perform this enhancement.

f) Add syntax-checking capabilities to the compiler so error messages are output when syntax errors are encountered in a Simple program. No modifications to the Simpletron simulator are required.

g) Allow arrays of integers. No modifications to the Simpletron simulator are required to perform this enhancement.

h) Allow subroutines specified by the Simple commands **`gosub`** and **`return`**. Command **`gosub`** passes program control to a subroutine and command **`return`** passes control back to the statement after the **`gosub`**. This is similar to a method call in Java. The same subroutine can be called from many **`gosub`** commands distributed throughout a program. No modifications to the Simpletron simulator are required.

i) Allow repetition structures of the form

```
for x = 2 to 10 step 2
    Simple statements
next
```

This **`for`** statement loops from **`2`** to **`10`** with an increment of **`2`**. The **`next`** line marks the end of the body of the **`for`** line. No modifications to the Simpletron simulator are required.

j) Allow repetition structures of the form

```
for x = 2 to 10
    Simple statements
next
```

This **`for`** statement loops from **`2`** to **`10`** with a default increment of **`1`**. No modifications to the Simpletron simulator are required.

k) Allow the compiler to process string input and output. This requires the Simpletron simulator to be modified to process and store string values. [*Hint*: Each Simpletron word (i.e., memory location) can be divided into two groups, each holding a two-digit integer. Each two-digit integer represents the Unicode decimal equivalent of a character. Add a machine-language instruction that will print a string beginning at a certain Simpletron memory location. The first half of the Simpletron word at that location is a count of the number of characters in the string (i.e., the length of the string). Each succeeding half word contains one Unicode character expressed as two decimal digits. The machine language instruction checks the length and prints the string by translating each two-digit number into its equivalent character.]

l) Allow the compiler to process floating-point values in addition to integers. The Simpletron Simulator must also be modified to process floating-point values.

19.30 (*A Simple Interpreter*) An interpreter is a program that reads a high-level language program statement, determines the operation to be performed by the statement and executes the operation immediately. The high-level language program is not converted into machine language first. Interpreters execute more slowly than compilers do, because each statement encountered in the program being interpreted must first be deciphered at execution time. If statements are contained in a loop, the statements are deciphered each time they are encountered in the loop. Early versions of the Basic programming language were implemented as interpreters. Most Java programs are run interpretively.

Write an interpreter for the Simple language discussed in Exercise 19.26. The program should use the infix-to-postfix converter developed in Exercise 19.12 and the postfix evaluator developed in Exercise 19.13 to evaluate expressions in a **`let`** statement. The same restrictions placed on the Simple language in Exercise 19.26 should be adhered to in this program. Test the interpreter with the Simple programs written in Exercise 19.26. Compare the results of running these programs in the interpreter with the results of compiling the Simple programs and running them in the Simpletron simulator built in Exercise 7.43.

19.31 *(Insert/Delete Anywhere in a Linked List)* Our linked-list class allowed insertions and deletions at only the front and the back of the linked list. These capabilities were convenient for us when we used inheritance or composition to produce a stack class and a queue class with a minimal amount

of code simply by reusing the list class. Linked lists are normally more general than those we provided. Modify the linked-list class we developed in this chapter to handle insertions and deletions anywhere in the list.

19.32 *(Lists and Queues without Tail References)* Our implementation of a linked list (Fig. 19.3) used both a **`firstNode`** and a **`lastNode`**. The **`lastNode`** was useful for the **`insertAtBack`** and **`removeFromBack`** methods of the **`List`** class. The **`insertAtBack`** method corresponds to the **`enqueue`** method of the **`Queue`** class.

Rewrite the **`List`** class so that it does not use a **`lastNode`**. Thus, any operations on the tail of a list must begin searching the list from the front. Does this affect our implementation of the **`Queue`** class (Fig. 19.13)?

19.33 *(Performance of Binary Tree Sorting and Searching)* One problem with the binary tree sort is that the order in which the data is inserted affects the shape of the tree—for the same collection of data, different orderings can yield binary trees of dramatically different shapes. The performance of the binary tree sorting and searching algorithms is sensitive to the shape of the binary tree. What shape would a binary tree have if its data were inserted in increasing order? in decreasing order? What shape should the tree have to achieve maximal searching performance?

19.34 *(Indexed Lists)* As presented in the text, linked lists must be searched sequentially. For large lists, this can result in poor performance. A common technique for improving list-searching performance is to create and maintain an index to the list. An index is a set of references to key places in the list. For example, an application that searches a large list of names could improve performance by creating an index with 26 entries—one for each letter of the alphabet. A search operation for a last name beginning with 'Y' would then first search the index to determine where the 'Y' entries begin, then "jump into" the list at that point and search linearly until the desired name is found. This would be much faster than searching the linked list from the beginning. Use the **`List`** class of Fig. 19.3 as the basis of an **`IndexedList`** class.

Write a program that demonstrates the operation of indexed lists. Be sure to include methods **`insertInIndexedList`**, **`searchIndexedList`** and **`deleteFromIndexedList`**.

20

Java Utilities Package and Bit Manipulation

Objectives

- To understand containers, such as classes **`Vector`** and **`Stack`**, and the **`Enumeration`** interface.
- To be able to create **`Hashtable`** objects and persistent hash tables called **`Properties`** objects.
- To understand random number generation with instances of class **`Random`**.
- To use bit manipulation and **`BitSet`** objects.

Nothing can have value without being an object of utility.
Karl Marx

I've been in Who's Who, and I know what's what, but this is the first time I ever made the dictionary.
Mae West

O! many a shaft at sent
Finds mark the archer little meant!
Sir Walter Scott

There was the Door to which I found no Key;
There was the Veil through which I might not see.
Edward FitzGerald, The Rubáiyát of Omar Khayyám, st. 32

"It's a poor sort of memory that only works backwards," the Queen remarked.
Lewis Carroll [Charles Lutwidge Dodgson]

Not by age but by capacity is wisdom acquired.
Titus Maccius Plautus, Trinummus, act II, sc. ii, l.88

Outline

20.1 Introduction
20.2 `Vector` Class and `Enumeration` Interface
20.3 `Stack` Class
20.4 `Dictionary` Class
20.5 `Hashtable` Class
20.6 `Properties` Class
20.7 `Random` Class
20.8 Bit Manipulation and the Bitwise Operators
20.9 `BitSet` Class

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

20.1 Introduction

This chapter discusses several utility classes and interfaces in package **`java.util`**, including class ***`Vector`***, interface ***`Enumeration`***, class ***`Stack`***, class ***`Dictionary`***, class ***`Hashtable`***, class ***`Properties`***, class ***`Random`*** and class ***`BitSet`***.

Programs use class **`Vector`** to create array-like objects that can grow and shrink dynamically as a program's data storage requirements change. We consider interface **`Enumeration`**, which enables a program to iterate through the elements of a container such as a **`Vector`**.

Class **`Stack`** offers conventional stack operations **`push`** and **`pop`**, as well as others we did not consider in Chapter 19.

Class **`Dictionary`** is an **`abstract`** class that provides a framework for storing keyed data in tables and retrieving that data. The chapter explains the theory of "hashing," a technique for rapidly storing and retrieving information from tables, and demonstrates the construction and manipulation of hash tables with Java's **`Hashtable`** class. Also, the chapter considers class **`Properties`**, which provides support for persistent hash tables—hash tables that can be written to a file with an output stream and read from a file with an input stream.

Class **`Random`** provides a richer collection of random number capabilities than is available with static method **`random`** of class **`Math`**.

The chapter presents an extensive discussion of bit manipulation operators, followed by a discussion of class **`BitSet`** that enables the creation of bit-array-like objects for setting and getting individual bit values.

Chapter 21, Collections, introduces a framework for manipulating groups of objects called *collections*. Objects of type **`Vector`**, **`Stack`** and **`Hashtable`** are collections.

20.2 `Vector` Class and `Enumeration` Interface

In most programming languages, including Java, conventional arrays are fixed in size—they cannot grow or shrink in response to an application's changing storage requirements. Java class ***`Vector`*** provides the capabilities of array-like data structures that can resize themselves dynamically.

At any time, the **Vector** contains a certain number of elements less than or equal to its *capacity*. The capacity is the space that has been reserved for the **Vector**'s elements. If a **Vector** requires additional capacity, it grows by a *capacity increment* that you specify or by a default assumed by the system. If you do not specify a capacity increment, the system will double the size of the **Vector** each time additional capacity is needed.

Performance Tip 20.1

*Inserting additional elements into a **Vector** whose current size is less than its capacity is a relatively fast operation.*

Performance Tip 20.2

*It is a relatively slow operation to insert an element into a **Vector** that needs to grow larger to accommodate the new element.*

Performance Tip 20.3

*The default capacity increment doubles the size of the **Vector**. This may seem a waste of storage, but it is actually an efficient way for many **Vector**s to grow quickly to be "about the right size." This is much more efficient time-wise than growing the **Vector** each time by only as much space as it takes to hold a single element. This disadvantage is that the **Vector** might occupy more space than it requires.*

Performance Tip 20.4

*If storage is at a premium, use **Vector** method **trimToSize** to trim a **Vector**'s capacity to the **Vector**'s exact size. This optimizes a **Vector**'s use of storage. However, adding another element to the **Vector** will force the **Vector** to grow dynamically—trimming leaves no room for growth.*

Vectors store references to **Object**s. Thus, a program can store references to any objects in a **Vector**. To store values of primitive data types in **Vector**s, use the type-wrapper classes (e.g., **Integer**, **Long**, **Float**) from package **java.lang** to create objects containing the primitive data type values.

Figure 20.1 demonstrates class **Vector** and several of its methods. The program provides a **JButton** that enables the user to test each of the methods. The user can type a **String** into the provided **JTextField**, and then press a button to see what the method does. Each operation displays a message in a **JLabel** to indicate the results of the operation.

```
1  // Fig. 20.1: VectorTest.java
2  // Testing the Vector class of the java.util package
3
4  // Java core packages
5  import java.util.*;
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class VectorTest extends JFrame {
13    private JLabel statusLabel;
```

Fig. 20.1 Demonstrating class **Vector** of package **java.util** (part 1 of 6).

```
14    private Vector vector;
15    private JTextField inputField;
16
17    // set up GUI to test Vector methods
18    public VectorTest()
19    {
20       super( "Vector Example" );
21
22       Container container = getContentPane();
23       container.setLayout( new FlowLayout() );
24
25       statusLabel = new JLabel();
26       vector = new Vector( 1 );
27
28       container.add( new JLabel( "Enter a string" ) );
29
30       inputField = new JTextField( 10 );
31       container.add( inputField );
32
33       // button to add element to vector
34       JButton addButton = new JButton( "Add" );
35
36       addButton.addActionListener(
37
38          new ActionListener() {
39
40             public void actionPerformed( ActionEvent event )
41             {
42                // add an element to vector
43                vector.addElement( inputField.getText() );
44                statusLabel.setText( "Added to end: " +
45                   inputField.getText() );
46                inputField.setText( "" );
47             }
48          }
49       ); // end call to addActionListener
50
51       container.add( addButton );
52
53       // button to remove element from vector
54       JButton removeButton = new JButton( "Remove" );
55
56       removeButton.addActionListener(
57
58          new ActionListener() {
59
60             public void actionPerformed( ActionEvent event )
61             {
62                // remove element from vector
63                if ( vector.removeElement( inputField.getText() ) )
64                   statusLabel.setText( "Removed: " +
65                      inputField.getText() );
```

Fig. 20.1 Demonstrating class **`Vector`** of package **`java.util`** (part 2 of 6).

```
66                   else
67                      statusLabel.setText( inputField.getText() +
68                         " not in vector" );
69                }
70             }
71          ); // end call to addActionListener
72
73          container.add( removeButton );
74
75          // button to get first element of vector
76          JButton firstButton = new JButton( "First" );
77
78          firstButton.addActionListener(
79
80             new ActionListener() {
81
82                public void actionPerformed( ActionEvent event )
83                {
84                   // return first element of vector
85                   try {
86                      statusLabel.setText(
87                         "First element: " + vector.firstElement() );
88                   }
89
90                   // catch exception if Vector empty
91                   catch ( NoSuchElementException exception ) {
92                      statusLabel.setText( exception.toString() );
93                   }
94                }
95             }
96          ); // end call to addActionListener
97
98          container.add( firstButton );
99
100         // button to get last element of vector
101         JButton lastButton = new JButton( "Last" );
102
103         lastButton.addActionListener(
104
105            new ActionListener() {
106
107               public void actionPerformed( ActionEvent event )
108               {
109                  // return last element of vector
110                  try {
111                     statusLabel.setText(
112                        "Last element: " + vector.lastElement() );
113                  }
114
115                  // catch exception if Vector empty
116                  catch ( NoSuchElementException exception ) {
117                     statusLabel.setText( exception.toString() );
118                  }
```

Fig. 20.1 Demonstrating class **`Vector`** of package **`java.util`** (part 3 of 6).

```
119            }
120         }
121      ); // end call to addActionListener
122
123      container.add( lastButton );
124
125      // button to determine whether vector is empty
126      JButton emptyButton = new JButton( "Is Empty?" );
127
128      emptyButton.addActionListener(
129
130         new ActionListener() {
131
132            public void actionPerformed( ActionEvent event )
133            {
134               // determine if Vector is empty
135               statusLabel.setText( vector.isEmpty() ?
136                  "Vector is empty" : "Vector is not empty" );
137            }
138         }
139      ); // end call to addActionListener
140
141      container.add( emptyButton );
142
143      // button to determine whether vector contains search key
144      JButton containsButton = new JButton( "Contains" );
145
146      containsButton.addActionListener(
147
148         new ActionListener() {
149
150            public void actionPerformed( ActionEvent event )
151            {
152               String searchKey = inputField.getText();
153
154               // determine if Vector contains searchKey
155               if ( vector.contains( searchKey ) )
156                  statusLabel.setText(
157                     "Vector contains " + searchKey );
158               else
159                  statusLabel.setText(
160                     "Vector does not contain " + searchKey );
161            }
162         }
163      ); // end call to addActionListener
164
165      container.add( containsButton );
166
167      // button to determine location of value in vector
168      JButton locationButton = new JButton( "Location" );
169
170      locationButton.addActionListener(
171
```

Fig. 20.1 Demonstrating class **`Vector`** of package **`java.util`** (part 4 of 6).

```
172          new ActionListener() {
173
174             public void actionPerformed( ActionEvent event )
175             {
176                // get location of an object in Vector
177                statusLabel.setText( "Element is at location " +
178                   vector.indexOf( inputField.getText() ) );
179             }
180          }
181       ); // end call to addActionListener
182
183       container.add( locationButton );
184
185       // button to trim vector size
186       JButton trimButton = new JButton( "Trim" );
187
188       trimButton.addActionListener(
189
190          new ActionListener() {
191
192             public void actionPerformed( ActionEvent event )
193             {
194                // remove unoccupied elements to save memory
195                vector.trimToSize();
196                statusLabel.setText( "Vector trimmed to size" );
197             }
198          }
199       );
200
201       container.add( trimButton );
202
203       // button to display vector size and capacity
204       JButton statsButton = new JButton( "Statistics" );
205
206       statsButton.addActionListener(
207
208          new ActionListener() {
209
210             public void actionPerformed( ActionEvent event )
211             {
212                // get size and capacity of Vector
213                statusLabel.setText( "Size = " + vector.size() +
214                   "; capacity = " + vector.capacity() );
215             }
216          }
217       ); // end call to addActionListener
218
219       container.add( statsButton );
220
221       // button to display vector contents
222       JButton displayButton = new JButton( "Display" );
223
224       displayButton.addActionListener(
```

Fig. 20.1 Demonstrating class **`Vector`** of package **`java.util`** (part 5 of 6).

```
225
226          new ActionListener() {
227
228             public void actionPerformed( ActionEvent event )
229             {
230                // use Enumeration to output Vector contents
231                Enumeration enum = vector.elements();
232                StringBuffer buf = new StringBuffer();
233
234                while ( enum.hasMoreElements() )
235                   buf.append( enum.nextElement() ).append( "   " );
236
237                JOptionPane.showMessageDialog( null,
238                   buf.toString(), "Display",
239                   JOptionPane.PLAIN_MESSAGE );
240             }
241          }
242       ); // end call to addActionListener
243
244       container.add( displayButton );
245       container.add( statusLabel );
246
247       setSize( 300, 200 );
248       setVisible( true );
249
250    }  // end VectorTest constructor
251
252    // execute application
253    public static void main( String args[] )
254    {
255       VectorTest application = new VectorTest();
256
257       application.setDefaultCloseOperation(
258          JFrame.EXIT_ON_CLOSE );
259    }
260
261 }  // end class VectorTest
```

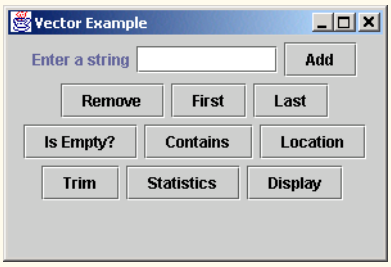


Fig. 20.1 Demonstrating class **`Vector`** of package **`java.util`** (part 6 of 6).

The application's constructor creates a **`Vector`** (line 26) with an initial capacity of one element. This **`Vector`** will double in size each time it needs to grow to accommodate more elements. Class **`Vector`** provides three other constructors. The no-argument constructor creates an empty **`Vector`** with an *initial capacity* of 10 elements. The constructor that takes two

arguments creates a **Vector** with an *initial capacity* specified by the first argument and a *capacity increment* specified by the second argument. Each time the **Vector** needs to grow, it will add space for the specified number of elements in the capacity increment. The constructor that takes a **Collection** allows creates a copy of a collection's elements and stores them in the **Vector**. In Chapter 21, we discuss **Collection**s.

Line 43 calls **Vector** method ***addElement*** to add its argument to the end of the **Vector**. If necessary, the **Vector** increases its capacity to accommodate the new element. Class **Vector** also provides method ***insertElementAt*** to insert an element at a specified position in the **Vector** and method ***setElementAt*** to set the element at a specific position in the **Vector**. Method **insertElementAt** makes room for the new element by shifting elements. Method **setElementAt** replaces the element at the specified position with its argument.

Line 63 calls **Vector** method ***removeElement*** to remove the first occurrence of its argument from the **Vector**. The method returns **true** if it finds the element in the **Vector**; otherwise, the method returns **false**. If the element is removed, all elements after that element in the **Vector** shift one position toward the beginning of the **Vector** to fill in the position of the removed element. Class **Vector** also provides method **removeAllElements** to remove every element from the **Vector** and method **removeElementAt** to remove the element at a specified index.

Line 87 calls **Vector** method ***firstElement*** to return a reference to the first element in the **Vector**. This method throws a **NoSuchElementException** if there are no elements currently in the **Vector**. Line 112 calls **Vector** method ***lastElement*** to return a reference to the last element in the **Vector**. This method throws a **NoSuchElementException** if there are no elements currently in the **Vector**.

Line 135 calls **Vector** method ***isEmpty*** to determine whether the **Vector** is empty. The method returns **true** if there are no elements in the **Vector**; otherwise, the method returns **false**.

Line 155 calls **Vector** method ***contains*** to determine whether the **Vector** contains the **searchKey** specified as an argument. Method **contains** returns **true** if **searchKey** is in the **Vector**; otherwise, the method returns **false**. Method **contains** uses **Object** method **equals** to determine whether the **searchKey** is equal to one of the **Vector**'s elements. Many classes override method **equals** to perform the comparisons in a manner specific to those classes. For example, class **String** defines **equals** to compare the individual characters in the two **String**s being compared. If method **equals** is not overridden, the original version from class **Object** is used. This version performs comparisons using operator **==** to determine whether two references refer to the same object in memory.

Line 178 calls **Vector** method ***indexOf*** to determine the index of the first location in the **Vector** containing the argument. The method returns **-1** if the argument is not found in the **Vector**. An overloaded version of this method takes a second argument specifying the index in the **Vector** at which the search should begin.

Performance Tip 20.5

Vector *methods* ***contains*** *and* ***indexOf*** *perform linear searches of a* ***Vector****'s contents, which are inefficient for large* ***Vector****s. If a program frequently searches for elements in a collection, consider using a* ***Hashtable*** *(see Section 20.5) or one of the Java Collection API's* ***Map*** *implementations (see Chapter 21).*

Line 195 calls **Vector** method ***trimToSize*** to reduce the capacity of the **Vector** to the current number of elements in the **Vector** (i.e., the **Vector**'s current size).

Lines 213–214 use **Vector** methods ***size*** and ***capacity*** to determine the number of elements currently in the **Vector** and the number of elements that can be stored in the **Vector** without allocating more memory, respectively.

Line 231 calls **Vector** method ***elements*** to return an ***Enumeration*** that enables the program to iterate through the **Vector**'s elements. An **Enumeration** provides two methods—***hasMoreElements*** and ***nextElement***. In line 234, method **hasMoreElements** returns **true** if there are more elements in the **Vector**. In line 235, method **nextElement** returns a reference to the next element in the **Vector**. If there are no more elements, method **nextElement** throws a **NoSuchElementException**.

For complete information on class **Vector** and its other methods, see the online Java API documentation.

20.3 Stack Class

In Chapter 19, Data Structures, we learned how to build such fundamental data structures as linked lists, stacks, queues and trees. In a world of software reuse, instead of building data structures as we need them, often we can take advantage of existing data structures. In this section, we investigate class ***Stack*** in the Java utilities package (**java.util**).

In Section 20.2, we discussed class **Vector**, which implements a dynamically resizable array. Class **Stack** extends class **Vector** to implement a stack data structure. As does **Vector**, class **Stack** stores references to **Object**s. To store primitive data types, use the appropriate type-wrapper class to create an object containing the primitive value (**Boolean**, **Byte**, **Character**, **Short**, **Integer**, **Long**, **Float** or **Double**). Figure 20.2 provides a GUI that enables the user to test each of the **Stack** methods.

```
1  // Fig. 20.2: StackTest.java
2  // Testing the Stack class of the java.util package
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.util.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class StackTest extends JFrame {
13    private JLabel statusLabel;
14    private JTextField inputField;
15    private Stack stack;
16
17    // create GUI to manipulate a Stack
18    public StackTest()
19    {
20       super( "Stacks" );
21
```

Fig. 20.2 Demonstrating class **Stack** of package **java.util** (part 1 of 5).

```
22          Container container = getContentPane();
23
24          statusLabel = new JLabel();
25          stack = new Stack();
26
27          container.setLayout( new FlowLayout() );
28          container.add( new JLabel( "Enter a string" ) );
29          inputField = new JTextField( 10 );
30          container.add( inputField );
31
32          // button to place object on stack
33          JButton pushButton = new JButton( "Push" );
34
35          pushButton.addActionListener(
36
37             new ActionListener() {
38
39                public void actionPerformed( ActionEvent event )
40                {
41                   // put object on Stack
42                   statusLabel.setText( "Pushed: " +
43                      stack.push( inputField.getText() ) );
44                }
45             }
46          );
47
48          container.add( pushButton );
49
50          // button to remove top object on stack
51          JButton popButton = new JButton( "Pop" );
52
53          popButton.addActionListener(
54
55             new ActionListener() {
56
57                public void actionPerformed( ActionEvent event )
58                {
59                   // remove element from Stack
60                   try {
61                      statusLabel.setText( "Popped: " + stack.pop() );
62                   }
63
64                   // process exception if Stack empty
65                   catch ( EmptyStackException exception ) {
66                      statusLabel.setText( exception.toString() );
67                   }
68                }
69             }
70          );
71
72          container.add( popButton );
73
```

Fig. 20.2 Demonstrating class **`Stack`** of package **`java.util`** (part 2 of 5).

```
74          // button to look at top element of stack
75          JButton peekButton = new JButton( "Peek" );
76
77          peekButton.addActionListener(
78
79             new ActionListener() {
80
81                public void actionPerformed( ActionEvent event )
82                {
83                   // look at top object on Stack
84                   try {
85                      statusLabel.setText( "Top: " + stack.peek() );
86                   }
87
88                   // process exception if Stack empty
89                   catch ( EmptyStackException exception ) {
90                      statusLabel.setText( exception.toString() );
91                   }
92                }
93             }
94          );
95
96          container.add( peekButton );
97
98          // button to determine whether stack is empty
99          JButton emptyButton = new JButton( "Is Empty?" );
100
101         emptyButton.addActionListener(
102
103            new ActionListener() {
104
105               public void actionPerformed( ActionEvent event )
106               {
107                  // determine if Stack is empty
108                  statusLabel.setText( stack.empty() ?
109                     "Stack is empty" : "Stack is not empty" );
110               }
111            }
112         );
113
114         container.add( emptyButton );
115
116         // button to determine whether search key is in stack
117         JButton searchButton = new JButton( "Search" );
118
119         searchButton.addActionListener(
120
121            new ActionListener() {
122
123               public void actionPerformed( ActionEvent event )
124               {
125                  // search Stack for specified object
126                  String searchKey = inputField.getText();
```

Fig. 20.2 Demonstrating class **`Stack`** of package **`java.util`** (part 3 of 5).

```
127                int result = stack.search( searchKey );
128
129                if ( result == -1 )
130                   statusLabel.setText( searchKey + " not found" );
131                else
132                   statusLabel.setText( searchKey +
133                      " found at element " + result );
134             }
135          }
136       );
137
138       container.add( searchButton );
139
140       // button to display stack contents
141       JButton displayButton = new JButton( "Display" );
142
143       displayButton.addActionListener(
144
145          new ActionListener() {
146
147             public void actionPerformed( ActionEvent event )
148             {
149                // output Stack contents
150                Enumeration enumeration = stack.elements();
151                StringBuffer buffer = new StringBuffer();
152
153                while ( enumeration.hasMoreElements() )
154                   buffer.append(
155                      enumeration.nextElement() ).append( " " );
156
157                JOptionPane.showMessageDialog( null,
158                    buffer.toString(), "Display",
159                    JOptionPane.PLAIN_MESSAGE );
160             }
161          }
162       );
163
164       container.add( displayButton );
165       container.add( statusLabel );
166
167       setSize( 675, 100 );
168       setVisible( true );
169    }
170
171    // execute application
172    public static void main( String args[] )
173    {
174       StackTest application = new StackTest();
175
176       application.setDefaultCloseOperation(
177          JFrame.EXIT_ON_CLOSE );
178    }
179
```

Fig. 20.2 Demonstrating class **`Stack`** of package **`java.util`** (part 4 of 5).

```
180 }  // end class StackTest
```

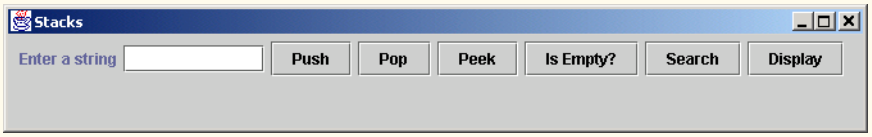


Fig. 20.2 Demonstrating class **`Stack`** of package **`java.util`** (part 5 of 5).

Line 25 creates an empty **`Stack`**. Line 43 calls **`Stack`** method ***`push`*** to add its argument to the top of the stack. The method returns an **`Object`** reference to its argument.

Line 61 calls **`Stack`** method ***`pop`*** to remove the top element of the stack. The method returns an **`Object`** reference to the removed element. If there are no elements in the **`Stack`**, method **`pop`** throws an ***`EmptyStackException`***.

Line 85 calls **`Stack`** method ***`peek`*** to view the top element of the stack without removing the element. Method **`peek`** returns an **`Object`** reference to the element.

Line 108 calls **`Stack`** method ***`empty`*** to determine whether the stack is empty. If it is empty, the method returns **`true`**; otherwise, the method returns **`false`**.

Line 127 calls **`Stack`** method ***`search`*** to determine whether its argument is in the stack. If so, the method returns the position of the element in the stack. *Note that the top element is position 1.* If the element is not in the stack, **`-1`** is returned.

The entire **`public`** interface of class **`Vector`** is actually part of class **`Stack`**, because **`Stack`** inherits from **`Vector`**. To prove this, our example provides a button to display the contents of the stack. This button invokes method **`elements`** to get an **`Enumeration`** of the stack; it then uses the **`Enumeration`** to walk through the stack elements.

Testing and Debugging Tip 20.1

`Stack` *extends* ***`Vector`****, so the user may perform operations on* ***`Stack`*** *objects that are ordinarily not allowed on conventional stack data structures. This could "corrupt" the elements of the* ***`Stack`*** *and destroy the integrity of the* ***`Stack`****.*

20.4 `Dictionary` Class

A ***`Dictionary`*** maps *keys* to *values*. When searching a **`Dictionary`** for a value, the program provides a key and the **`Dictionary`** returns the corresponding value. **`Dictionary`** is an **`abstract`** class. In particular, it is the superclass of class **`Hashtable`**, which we discuss in Section 20.5. Class **`Dictionary`** provides the **`public`** interface methods required to maintain a table of *key–value pairs* where the keys help store and retrieve the values in the table. Each key in the table is unique. The data structure is similar to a dictionary of words and definitions—the word is the *key* that is used to look up the definition (i.e., the *value*).

`Dictionary` method **`size`** returns the number of key–value pairs in a **`Dictionary`** object. Method ***`isEmpty`*** returns **`true`** if a **`Dictionary`** is empty, and **`false`** otherwise. Method ***`keys`*** returns an **`Enumeration`** that a program can use to iterate through a **`Dictionary`**'s keys. Method **`elements`** returns an **`Enumeration`** that a program can use to iterate through a **`Dictionary`**'s values. Method ***`get`*** returns the object that corresponds to a given key value. Method ***`put`*** puts an object associated with a given key into the table. Method ***`remove`*** removes an element corresponding to a given key and returns a reference to it.

20.5 `Hashtable` Class

Object-oriented programming languages facilitate creating new data types. When a program creates objects of new or existing types, the program then needs to manage those objects efficiently. This includes storing and retrieving objects. Storing and retrieving information with arrays is efficient if some aspect of your data directly matches the key value and if those keys are unique and tightly packed. If you have 100 employees with 9-digit Social Security numbers and you want to store and retrieve employee data by using the Social Security number as a key, it would nominally require an array with 999,999,999 elements, because there are 999,999,999 unique 9-digit numbers. This is impractical for virtually all applications that use Social Security numbers as keys. If the program could have an array that large, the program could get high performance for both storing and retrieving employee records by simply using the Social Security number as the array index.

There are numerous applications that have this problem, namely, that either the keys are of the wrong type (i.e., not nonnegative integers), or they may be of the right type, but sparsely spread over a huge range.

What is needed is a high-speed scheme for converting keys such as Social Security numbers, inventory part numbers and the like into unique array subscripts. Then, when an application needs to store something, the scheme could convert the application key rapidly into a subscript and the record of information could be stored at that slot in the array. Retrieval is accomplished the same way: Once the application has a key for which it wants to retrieve the data record, the application simply applies the conversion to the key—this produces the array subscript where the data is stored and the data is retrieved.

The scheme we describe here is the basis of a technique called *hashing*. Why the name? When we convert a key into an array subscript, we literally scramble the bits, forming a kind of "mishmashed" number. The number actually has no real significance beyond its usefulness in storing and retrieving this particular number data record.

A glitch in the scheme occurs when *collisions* occur (i.e., when two different keys "hash into" the same cell (or element) in the array). We cannot store two different data records in the same space, so we need to find an alternative home for all records beyond the first that hash to a particular array subscript. There are many schemes for doing this. One is to "hash again" (i.e., to reapply the hashing transformation to the key to provide a next candidate cell in the array). The hashing process is designed to distribute the values throughout the table, so the assumption is that with just a few hashes an available cell will be found.

Another scheme uses one hash to locate the first candidate cell. If that cell is occupied, successive cells are searched linearly until an available cell is found. Retrieval works the same way: The key is hashed once to determine the initial location to check to see whether it contains the desired data. If it does, the search is finished. If it does not, successive cells are searched linearly until the desired data is found.

The most popular solution to hash table collisions is to have each cell of the table be a hash "bucket," typically a linked list of all the key–value pairs that hash to that cell. This is the solution that Java's **`Hashtable`** class (from package **`java.util`**) implements.

One factor that affects the performance of hashing schemes is called the *load factor*. This is the ratio of the number of occupied cells in the hash table to the size of the hash table. The closer this ratio gets to 1.0, the greater the chance of collisions.

Performance Tip 20.6

The load factor in a hash table is a classic example of a space–time trade-off: By increasing the load factor, we get better memory utilization, but the program runs slower, due to increased hashing collisions. By decreasing the load factor, we get better program speed, because of reduced hashing collisions, but we get poorer memory utilization, because a larger portion of the hash table remains empty.

The complexity of programming hash tables properly is too much for most casual programmers. Computer science students study hashing schemes thoroughly in courses called "Data Structures" or "Algorithms." Recognizing the value of hashing to most programmers, Java provides class **`Hashtable`** and some related features to enable programmers to use hashing without having to implement the messy details.

Actually, the preceding sentence is profoundly important in our study of object-oriented programming. As discussed in earlier chapters, classes encapsulate and hide complexity (i.e., implementation details) and offer user-friendly interfaces. Crafting classes to do this properly is one of the most valued skills in the field of object-oriented programming.

Figure 20.3 provides a GUI that enables you to test several **`Hashtable`** methods. Line 25 creates an empty **`Hashtable`** with a default capacity of 101 elements and a default load factor of .75. When the number of occupied slots in the **`Hashtable`** becomes more than the capacity times the load factor, the table grows larger. Class **`Hashtable`** also provides a constructor that takes one argument specifying the capacity and a constructor that takes two arguments, specifying the capacity and load factor, respectively.

```
1  // Fig. 20.3: HashtableTest.java
2  // Demonstrates class Hashtable of the java.util package.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.util.*;
8
9  // Java extensions packages
10 import javax.swing.*;
11
12 public class HashtableTest extends JFrame {
13    private JLabel statusLabel;
14    private Hashtable table;
15    private JTextArea displayArea;
16    private JTextField lastNameField;
17    private JTextField firstNameField;
18
19    // set up GUI to demonstrate Hashtable features
20    public HashtableTest()
21    {
22       super( "Hashtable Example" );
23
24       statusLabel = new JLabel();
25       table = new Hashtable();
26       displayArea = new JTextArea( 4, 20 );
```

Fig. 20.3 Demonstrating class **`Hashtable`** (part 1 of 6).

```
27          displayArea.setEditable( false );
28
29          JPanel northSubPanel = new JPanel();
30
31          northSubPanel.add( new JLabel( "First name" ) );
32          firstNameField = new JTextField( 8 );
33          northSubPanel.add( firstNameField );
34
35          northSubPanel.add( new JLabel( "Last name (key)" ) );
36          lastNameField = new JTextField( 8 );
37          northSubPanel.add( lastNameField );
38
39          JPanel northPanel = new JPanel();
40          northPanel.setLayout( new BorderLayout() );
41          northPanel.add( northSubPanel, BorderLayout.NORTH );
42          northPanel.add( statusLabel, BorderLayout.SOUTH );
43
44          JPanel southPanel = new JPanel();
45          southPanel.setLayout( new GridLayout( 2, 5 ) );
46          JButton putButton = new JButton( "Put" );
47
48          putButton.addActionListener(
49
50             new ActionListener() {
51
52                // add new key/value pair to hash table
53                public void actionPerformed( ActionEvent event )
54                {
55                   Employee employee = new Employee(
56                      firstNameField.getText(),
57                      lastNameField.getText() );
58
59                   Object value =
60                      table.put( lastNameField.getText(), employee );
61
62                   // first time this key was added
63                   if ( value == null )
64                      statusLabel.setText(
65                         "Put: " + employee.toString() );
66
67                   // replaced previous value for this key
68                   else
69                      statusLabel.setText(
70                         "Put: " + employee.toString() +
71                         "; Replaced: " + value.toString() );
72                }
73             }
74          );
75
76          southPanel.add( putButton );
77
78          // button to get value for specific key
79          JButton getButton = new JButton( "Get" );
```

Fig. 20.3 Demonstrating class **`Hashtable`** (part 2 of 6).

```
80
81          getButton.addActionListener(
82
83             new ActionListener() {
84
85                // get value for specific key
86                public void actionPerformed( ActionEvent event )
87                {
88                   Object value = table.get( lastNameField.getText() );
89
90                   // value found for key
91                   if ( value != null )
92                      statusLabel.setText(
93                         "Get: " + value.toString() );
94
95                   // value not found for key
96                   else
97                      statusLabel.setText(
98                         "Get: " + lastNameField.getText() +
99                         " not in table" );
100               }
101            }
102         );
103
104         southPanel.add( getButton );
105
106         // button to remove key/value pair from table
107         JButton removeButton = new JButton( "Remove" );
108
109         removeButton.addActionListener(
110
111            new ActionListener() {
112
113               // remove key/value pair
114               public void actionPerformed( ActionEvent event )
115               {
116                  Object value =
117                     table.remove( lastNameField.getText() );
118
119                  // key found
120                  if ( value != null )
121                     statusLabel.setText( "Remove: " +
122                        value.toString() );
123
124                  // key not found
125                  else
126                     statusLabel.setText( "Remove: " +
127                        lastNameField.getText() + " not in table" );
128               }
129            }
130         );
131
132         southPanel.add( removeButton );
```

Fig. 20.3 Demonstrating class **`Hashtable`** (part 3 of 6).

```
133
134         // button to detetmine whether hash table is empty
135         JButton emptyButton = new JButton( "Empty" );
136
137         emptyButton.addActionListener(
138
139            new ActionListener() {
140
141               // determine whether hash table is empty
142               public void actionPerformed( ActionEvent event )
143               {
144                  statusLabel.setText( "Empty: " + table.isEmpty() );
145               }
146            }
147         );
148
149         southPanel.add( emptyButton );
150
151         // button to determine whether hash table contains key
152         JButton containsKeyButton = new JButton( "Contains key" );
153
154         containsKeyButton.addActionListener(
155
156            new ActionListener() {
157
158               // determine whether hash table contains key
159               public void actionPerformed( ActionEvent event )
160               {
161                  statusLabel.setText( "Contains key: " +
162                     table.containsKey( lastNameField.getText() ) );
163               }
164            }
165         );
166
167         southPanel.add( containsKeyButton );
168
169         // button to clear all hash table contents
170         JButton clearButton = new JButton( "Clear table" );
171
172         clearButton.addActionListener(
173
174            new ActionListener() {
175
176               // clear hash table contents
177               public void actionPerformed( ActionEvent event )
178               {
179                  table.clear();
180                  statusLabel.setText( "Clear: Table is now empty" );
181               }
182            }
183         );
184
185         southPanel.add( clearButton );
```

Fig. 20.3 Demonstrating class **`Hashtable`** (part 4 of 6).

```
186
187         // button to display hash table elements
188         JButton listElementsButton = new JButton( "List objects" );
189
190         listElementsButton.addActionListener(
191
192            new ActionListener() {
193
194               // display hash table elements
195               public void actionPerformed( ActionEvent event )
196               {
197                  StringBuffer buffer = new StringBuffer();
198
199                  for ( Enumeration enumeration = table.elements();
200                        enumeration.hasMoreElements(); )
201                     buffer.append(
202                        enumeration.nextElement() ).append( '\n' );
203
204                  displayArea.setText( buffer.toString() );
205               }
206            }
207         );
208
209         southPanel.add( listElementsButton );
210
211         // button to display hash table keys
212         JButton listKeysButton = new JButton( "List keys" );
213
214         listKeysButton.addActionListener(
215
216            new ActionListener() {
217
218               // display hash table KEYS
219               public void actionPerformed( ActionEvent event )
220               {
221                  StringBuffer buffer = new StringBuffer();
222
223                  for ( Enumeration enumeration = table.keys();
224                        enumeration.hasMoreElements(); )
225                     buffer.append(
226                        enumeration.nextElement() ).append( '\n' );
227
228                  JOptionPane.showMessageDialog( null,
229                     buffer.toString(), "Display",
230                     JOptionPane.PLAIN_MESSAGE );
231               }
232            }
233         );
234
235         southPanel.add( listKeysButton );
236
237         Container container = getContentPane();
238         container.add( northPanel, BorderLayout.NORTH );
```

Fig. 20.3 Demonstrating class **`Hashtable`** (part 5 of 6).

```
239         container.add( new JScrollPane( displayArea ),
240            BorderLayout.CENTER );
241         container.add( southPanel, BorderLayout.SOUTH );
242
243         setSize( 540, 300 );
244         setVisible( true );
245      }
246
247      // execute application
248      public static void main( String args[] )
249      {
250         HashtableTest application = new HashtableTest();
251
252         application.setDefaultCloseOperation(
253            JFrame.EXIT_ON_CLOSE );
254      }
255
256   }  // end class HashtableTest
257
258   // Employee class to represent first and last name
259   class Employee {
260      private String first, last;
261
262      // initialize an Employee
263      public Employee( String firstName, String lastName )
264      {
265         first = firstName;
266         last = lastName;
267      }
268
269      // convert Employee to String representation
270      public String toString()
271      {
272         return first + " " + last;
273      }
274
275   }  // end class Employee
```

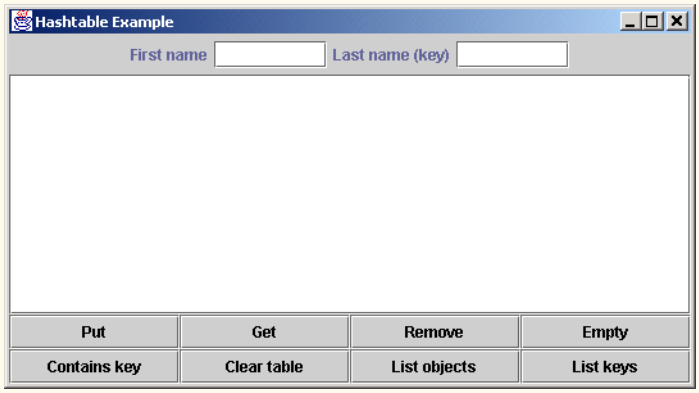


Fig. 20.3 Demonstrating class **Hashtable** (part 6 of 6).

Lines 59–60 call **Hashtable** method ***put*** to add a *key* (the first argument) and a *value* (the second argument) into the **Hashtable**. Method **put** returns **null** if key has not been inserted in the **Hashtable** previously. Otherwise, method **put** returns the original value for that key in the **Hashtable**; this helps the program manage cases in which it intends to replace the value stored for a given key. If either the key or the value is **null**, a **NullPointerException** occurs.

Line 88 calls **Hashtable** method ***get*** to locate the value associated with the key specified as an argument. If the key is present in the table, **get** returns an **Object** reference to the corresponding value; otherwise, the method returns **null**.

Lines 116–117 call **Hashtable** method ***remove*** to remove a key–value pair from the table. The method returns a reference to the removed **Object**. If there is no value mapped to the specified key, the method returns **null**.

Line 144 calls **Hashtable** method **isEmpty**, which returns **true** if the **Hashtable** is empty; otherwise it returns **false**.

Line 162 calls **Hashtable** method ***containsKey*** to determine whether the key specified as an argument is in the **Hashtable** (i.e., a value is associated with that key). If so, the method returns **true**; otherwise, the method returns **false**. Class **Hashtable** also provides method ***contains*** to determine whether the **Object** specified as its argument is in the **Hashtable**.

Line 179 calls **Hashtable** method ***clear*** to empty the **Hashtable** contents. Line 199 calls **Hashtable** method ***elements*** to obtain an **Enumeration** of the values in the **Hashtable**. Line 223 calls **Hashtable** method ***keys*** to obtain an **Enumeration** of the keys in the **Hashtable**.

For more information on class **Hashtable** and its methods, see the online Java API documentation.

20.6 Properties Class

A ***Properties*** object is a persistent **Hashtable** object that normally stores key–value pairs of **String**s—assuming that you use methods ***setProperty*** and ***getProperty*** to manipulate the table rather than **Hashtable** methods **put** and **get**. By persistent, we mean that the **Hashtable** object can be written to an output stream and directed to a file, and read back in through an input stream. In fact, most objects in Java can now be output and input with Java's object serialization (see Chapter 16). The **Properties** class extends class **Hashtable**, so **Properties** objects have the methods we discussed in Fig. 20.3. The keys and values in a **Properties** object must be of type **String**. Class **Properties** provides some additional methods that are demonstrated in Fig. 20.4.

```
1  // Fig. 20.4: PropertiesTest.java
2  // Demonstrates class Properties of the java.util package.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.io.*;
8  import java.util.*;
```

Fig. 20.4 Demonstrating class **Properties** (part 1 of 6).

```
 9
10  // Java extension packages
11  import javax.swing.*;
12
13  public class PropertiesTest extends JFrame {
14     private JLabel statusLabel;
15     private Properties table;
16     private JTextArea displayArea;
17     private JTextField valueField, nameField;
18
19     // set up GUI to test Properties table
20     public PropertiesTest()
21     {
22        super( "Properties Test" );
23
24        // create Properties table
25        table = new Properties();
26
27        Container container = getContentPane();
28
29        // set up NORTH of window's BorderLayout
30        JPanel northSubPanel = new JPanel();
31
32        northSubPanel.add( new JLabel( "Property value" ) );
33        valueField = new JTextField( 10 );
34        northSubPanel.add( valueField );
35
36        northSubPanel.add( new JLabel( "Property name (key)" ) );
37        nameField = new JTextField( 10 );
38        northSubPanel.add( nameField );
39
40        JPanel northPanel = new JPanel();
41        northPanel.setLayout( new BorderLayout() );
42        northPanel.add( northSubPanel, BorderLayout.NORTH );
43
44        statusLabel = new JLabel();
45        northPanel.add( statusLabel, BorderLayout.SOUTH );
46
47        container.add( northPanel, BorderLayout.NORTH );
48
49        // set up CENTER of window's BorderLayout
50        displayArea = new JTextArea( 4, 35 );
51        container.add( new JScrollPane( displayArea ),
52           BorderLayout.CENTER );
53
54        // set up SOUTH of window's BorderLayout
55        JPanel southPanel = new JPanel();
56        southPanel.setLayout( new GridLayout( 1, 5 ) );
57
58        // button to put a name/value pair in Properties table
59        JButton putButton = new JButton( "Put" );
60
```

Fig. 20.4 Demonstrating class **`Properties`** (part 2 of 6).

```
61          putButton.addActionListener(
62
63             new ActionListener() {
64
65                // put name/value pair in Properties table
66                public void actionPerformed( ActionEvent event )
67                {
68                   Object value = table.setProperty(
69                      nameField.getText(), valueField.getText() );
70
71                   if ( value == null )
72                      showstatus( "Put: " + nameField.getText() +
73                         " " + valueField.getText() );
74
75                   else
76                      showstatus( "Put: " + nameField.getText() +
77                         " " + valueField.getText() +
78                         "; Replaced: " + value.toString() );
79
80                   listProperties();
81                }
82             }
83          ); // end call to addActionListener
84
85          southPanel.add( putButton );
86
87          // button to empty contents of Properties table
88          JButton clearButton = new JButton( "Clear" );
89
90          clearButton.addActionListener(
91
92             new ActionListener() {
93
94                // use method clear to empty table
95                public void actionPerformed( ActionEvent event )
96                {
97                   table.clear();
98                   showstatus( "Table in memory cleared" );
99                   listProperties();
100               }
101            }
102         ); // end call to addActionListener
103
104         southPanel.add( clearButton );
105
106         // button to get value of a property
107         JButton getPropertyButton = new JButton( "Get property" );
108
109         getPropertyButton.addActionListener(
110
111            new ActionListener() {
112
```

Fig. 20.4 Demonstrating class **`Properties`** (part 3 of 6).

```
113             // use method getProperty to obtain a property value
114             public void actionPerformed( ActionEvent event )
115             {
116                Object value = table.getProperty(
117                   nameField.getText() );
118
119                if ( value != null )
120                   showstatus( "Get property: " +
121                      nameField.getText() + " " +
122                      value.toString() );
123
124                else
125                   showstatus( "Get: " + nameField.getText() +
126                      " not in table" );
127
128                listProperties();
129             }
130          }
131       ); // end call to addActionListener
132
133       southPanel.add( getPropertyButton );
134
135       // button to contents of Properties table to file
136       JButton saveButton = new JButton( "Save" );
137
138       saveButton.addActionListener(
139
140          new ActionListener() {
141
142             // use method save to place contents in file
143             public void actionPerformed( ActionEvent event )
144             {
145                // save contents of table
146                try {
147                   FileOutputStream output =
148                      new FileOutputStream( "props.dat" );
149
150                   table.store( output, "Sample Properties" );
151                   output.close();
152
153                   listProperties();
154                }
155
156                // process problems with file output
157                catch( IOException ioException ) {
158                   ioException.printStackTrace();
159                }
160             }
161          }
162       ); // end call to addActionListener
163
164       southPanel.add( saveButton );
165
```

Fig. 20.4 Demonstrating class **`Properties`** (part 4 of 6).

```
166       // button to load contents of Properties table from file
167       JButton loadButton = new JButton( "Load" );
168
169       loadButton.addActionListener(
170
171          new ActionListener() {
172
173             // use method load to read contents from file
174             public void actionPerformed( ActionEvent event )
175             {
176                // load contents of table
177                try {
178                   FileInputStream input =
179                      new FileInputStream( "props.dat" );
180
181                   table.load( input );
182                   input.close();
183                   listProperties();
184                }
185
186                // process problems with file input
187                catch( IOException ioException ) {
188                   ioException.printStackTrace();
189                }
190             }
191          }
192       ); // end call to addActionListener
193
194       southPanel.add( loadButton );
195
196       container.add( southPanel, BorderLayout.SOUTH );
197
198       setSize( 550, 225 );
199       setVisible( true );
200    }
201
202    // output property values
203    public void listProperties()
204    {
205       StringBuffer buffer = new StringBuffer();
206       String name, value;
207
208       Enumeration enumeration = table.propertyNames();
209
210       while ( enumeration.hasMoreElements() ) {
211          name = enumeration.nextElement().toString();
212          value = table.getProperty( name );
213
214          buffer.append( name ).append( '\t' );
215          buffer.append( value ).append( '\n' );
216       }
217
218       displayArea.setText( buffer.toString() );
```

Fig. 20.4 Demonstrating class **Properties** (part 5 of 6).

```
219     }  // end method ListProperties
220
221     // display String in statusLabel label
222     public void showstatus( String s )
223     {
224        statusLabel.setText( s );
225     }
226
227     // execute application
228     public static void main( String args[] )
229     {
230        PropertiesTest application = new PropertiesTest();
231
232        application.setDefaultCloseOperation(
233           JFrame.EXIT_ON_CLOSE );
234     }
235
236  }  // end class PropertiesTest
```

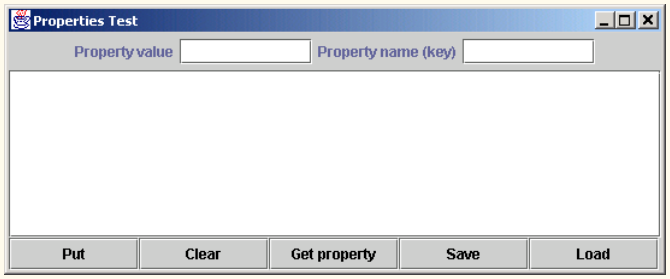


Fig. 20.4 Demonstrating class **Properties** (part 6 of 6).

Line 25 uses the no-argument constructor to create an empty **Properties** table with no default properties. Class **Properties** also provides an overloaded constructor that receives a reference to a **Properties** object containing default property values.

Lines 68–69 call **Properties** method **setProperty** to store a value for the specified key. If the key does not exist in the table, **setProperty** returns **null**; otherwise, it returns the previous value for that key.

Lines 116–117 call **Properties** method ***getProperty*** to locate the value associated with the specified key. If the key is not found in this **Properties** object, **getProperty** uses the one in the default **Properties** object (if there is one). The process continues recursively until there are no more default **Properties** objects (remember that every **Properties** object can be initialized with a default **Properties** object), at which point **getProperty** returns **null**. An overloaded version of this method receives two arguments, the second of which is the default value to return if **getProperty** cannot locate the key.

Line 150 calls **Properties** method ***store*** to save the contents of the **Properties** object to the **OutputStream** object specified as the first argument (in this case, a **FileOutputStream**). The **String** argument is a description of the **Properties** object. Class **Properties** also provides method ***list***, which takes a **PrintStream** argument. This method is useful for displaying the set of properties.

Testing and Debugging Tip 20.2

Use **`Properties`** *method* **`list`** *to display the contents of a* **`Properties`** *object for debugging purposes.*

Line 181 calls **`Properties`** method ***`load`*** to restore the contents of the **`Properties`** object from the **`InputStream`** specified as the first argument (in this case, a **`FileInputStream`**).

Line 208 calls **`Properties`** method ***`propertyNames`*** to obtain an **`Enumeration`** of the property names. The value of each property can be determined by using method **`getProperty`**.

20.7 `Random` Class

We discussed random-number generation in Chapter 6, Methods, where we used **`Math`** class method **`random`**. Java provides extensive additional random number generation capabilities in class ***`Random`***. We briefly walk through the API calls here.

A new random-number generator can be created by using

```
Random r = new Random();
```

This form uses the computer's current time to seed its random-number generator differently during each constructor call and thus generates different sequences of random numbers for each **`Random`** object.

To create a pseudorandom-number generator with "repeatability," use

```
Random r = new Random( seedValue );
```

The **`seedValue`** argument (type **`long`**) is used in the random number calculation to "seed" the random number generator. If the same **`seedValue`** is used every time, the **`Random`** object produces the same sequence of random numbers.

Testing and Debugging Tip 20.3

While a program is under development, use the form ***`Random(seedValue)`*** *that produces a repeatable sequence of random numbers. If a bug occurs, fix the bug and test with the same* **`seedValue`***; this allows you to reconstruct the exact same sequence of random numbers that caused the bug. Once the bugs have been removed, use the form* ***`Random()`****, which generates a new sequence of random numbers each time the program is run.*

The call

```
r.setSeed( seedValue );
```

resets **`r`**'s seed value at any time.

The calls

```
r.nextInt()
r.nextLong()
```

generate uniformly distributed random integers. You can use **`Math.abs`** to take the absolute value of the number produced by ***`nextInt`***, thus giving a number in the range from zero through approximately 2 billion. Then use the **`%`** operator to scale the number. For example, to roll a six-sided die, if you scale with a 6, you will get a number in the range from

0 through 5. Then simply shift this value by adding 1 to produce a number in the range from 1 through 6. The expression is as follows:

```
Math.abs( r.nextInt() ) % 6 + 1
```

The calls

```
r.nextFloat()
r.nextDouble()
```

generate uniformly distributed values in the range 0.0 <= *x* < 1.0.

The call

```
r.nextGaussian()
```

generates a **double** value with a probability density of a *Gaussian* (i.e., "normal") distribution (mean of 0.0 and standard deviation of 1.0).

20.8 Bit Manipulation and the Bitwise Operators

Java provides extensive bit-manipulation capabilities for programmers who need to get down to the so-called "bits-and-bytes" level. Operating systems, test equipment software, networking software and many other kinds of software require that the programmer communicate "directly with the hardware." In this section and the next, we discuss Java's bit-manipulation capabilities. We introduce Java's bitwise operators, and we demonstrate their use in live-code examples.

Computers represent all data internally as sequences of bits. Each bit can assume the value **0** or the value **1**. On most systems, a sequence of 8 bits forms a byte—the standard storage unit for a variable of type **byte**. Other data types are stored in larger numbers of bytes. The bitwise operators can manipulate the bits of integral operands (i.e., those having type **byte**, **char**, **short**, **int** and **long**).

Note that the bitwise operator discussions in this section show the binary representations of the integer operands. For a detailed explanation of the binary (also called base 2) number system, see Appendix E, Number Systems.

The bitwise operators are *bitwise AND* (**&**), *bitwise inclusive OR* (**|**), *bitwise exclusive OR* (**^**), *left shift* (**<<**), *right shift with sign extension* (**>>**), *right shift with zero extension* (**>>>**) and complement (**~**). The bitwise AND, bitwise inclusive OR and bitwise exclusive OR operators compare their two operands bit by bit. The bitwise AND operator sets each bit in the result to 1 if the corresponding bit in both operands is 1. The bitwise inclusive OR operator sets each bit in the result to 1 if the corresponding bit in either (or both) operand(s) is 1. The bitwise exclusive OR operator sets each bit in the result to 1 if the corresponding bit in exactly one operand is 1. The left shift operator shifts the bits of its left operand to the left by the number of bits specified in its right operand. The right shift operator with sign extension shifts the bits in its left operand to the right by the number of bits specified in its right operand—if the left operand is negative, **1**s are shifted in from the left; otherwise, **0**s are shifted in from the left. The right shift operator with zero extension shifts the bits in its left operand to the right by the number of bits specified in its right operand—**0**s are shifted in from the left. The bitwise complement operator sets all **0** bits in its operand to **1** in the result and sets all **1** bits to **0** in the result. Detailed discussions of each bitwise operator appear in the following examples. The bitwise operators are summarized in Fig. 20.5.

Operator	Name	Description
`&`	bitwise AND	The bits in the result are set to `1` if the corresponding bits in the two operands are both `1`.
`|`	bitwise inclusive OR	The bits in the result are set to `1` if at least one of the corresponding bits in the two operands is `1`.
`^`	bitwise exclusive OR	The bits in the result are set to `1` if exactly one of the corresponding bits in the two operands is `1`.
`<<`	left shift	Shifts the bits of the first operand left by the number of bits specified by the second operand; fill from the right with `0` bits.
`>>`	right shift with sign extension	Shifts the bits of the first operand right by the number of bits specified by the second operand. If the first operand is negative, `1`s are shifted in from the left; otherwise, `0`s are shifted in from the left.
`>>>`	right shift with zero extension	Shifts the bits of the first operand right by the number of bits specified by the second operand; `0`s are shifted in from the left.
`~`	one's complement	All `0` bits are set to `1` and all `1` bits are set to `0`.

Fig. 20.5 The bitwise operators .

When using the bitwise operators, it is useful to display values in their binary representation to illustrate the effects of these operators. The application of Fig. 20.6 allows the user to enter an integer into a **`JTextField`** and press *Enter*. Method **`actionPerformed`** (lines 32–36) reads the **`String`** from the **`JTextField`**, converts it to an integer and invokes method **`getBits`** (lines 55–80) to obtain a **`String`** representation of the integer in bits. The result is displayed in the output **`JTextField`**. The integer is displayed in its binary representation in groups of eight bits each. Method **`getBits`** uses the bitwise AND operator to combine variable **`value`** with variable **`displayMask`**. Often, the bitwise AND operator is used with an operand called a *mask*—an integer value with specific bits set to `1`. Masks are used to hide some bits in a value while selecting other bits. In **`getBits`**, mask variable **`displayMask`** is assigned the value **`1 << 31`** or

```
10000000 00000000 00000000 00000000
```

The left shift operator shifts the value `1` from the low-order (rightmost) bit to the high-order (leftmost) bit in **`displayMask`** and fills in `0` bits from the right.

```
1  // Fig. 20.6: PrintBits.java
2  // Printing an unsigned integer in bits
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
```

Fig. 20.6 Printing the bits in an integer (part 1 of 3).

```
 7
 8  // Java extension packages
 9  import javax.swing.*;
10
11  public class PrintBits extends JFrame {
12     private JTextField outputField;
13
14     // set up GUI
15     public PrintBits()
16     {
17        super( "Printing bit representations for numbers" );
18
19        Container container = getContentPane();
20        container.setLayout( new FlowLayout() );
21
22        container.add( new JLabel( "Enter an integer " ) );
23
24        // textfield to read value from user
25        JTextField inputField = new JTextField( 10 );
26
27        inputField.addActionListener(
28
29           new ActionListener() {
30
31              // read integer and get bitwise representation
32              public void actionPerformed( ActionEvent event )
33              {
34                 int value = Integer.parseInt(
35                    event.getActionCommand() );
36                 outputField.setText( getBits( value ) );
37              }
38           }
39        );
40
41        container.add( inputField );
42
43        container.add( new JLabel( "The integer in bits is" ) );
44
45        // textfield to display integer in bitwise form
46        outputField = new JTextField( 33 );
47        outputField.setEditable( false );
48        container.add( outputField );
49
50        setSize( 720, 70 );
51        setVisible( true );
52     }
53
54     // display bit representation of specified int value
55     private String getBits( int value )
56     {
57        // create int value with 1 in leftmost bit and 0s elsewhere
58        int displayMask = 1 << 31;
59
```

Fig. 20.6 Printing the bits in an integer (part 2 of 3).

```
60          // buffer to build output
61          StringBuffer buffer = new StringBuffer( 35 );
62
63          // for each bit append 0 or 1 to buffer
64          for ( int bit = 1; bit <= 32; bit++ ) {
65
66             // use displayMask to isolate bit and determine whether
67             // bit has value of 0 or 1
68             buffer.append(
69                ( value & displayMask ) == 0 ? '0' : '1' );
70
71             // shift value one position to left
72             value <<= 1;
73
74             // append space to buffer every 8 bits
75             if ( bit % 8 == 0 )
76                buffer.append( ' ' );
77          }
78
79          return buffer.toString();
80       }
81
82       // execute application
83       public static void main( String args[] )
84       {
85          PrintBits application = new PrintBits();
86
87          application.setDefaultCloseOperation(
88             JFrame.EXIT_ON_CLOSE );
89       }
90
91    }  // end class PrintBits
```

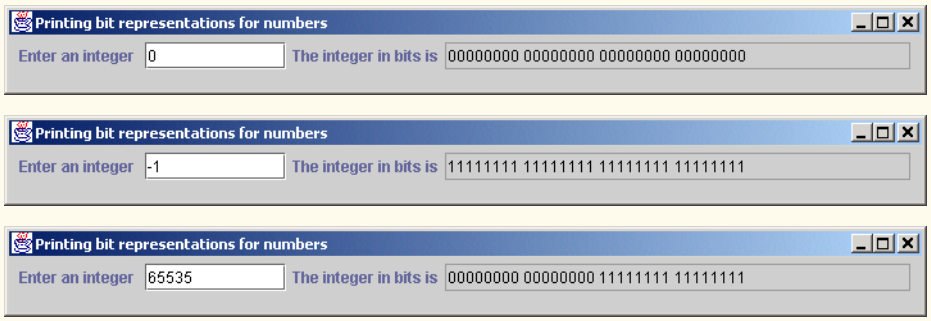


Fig. 20.6 Printing the bits in an integer (part 3 of 3).

Lines 68–69 append a **1** or a **0** to a **StringBuffer** for the current leftmost bit of variable **value**. Assume that **value** contains **4000000000** (**11101110 01101011 00101000 00000000**). When **value** and **displayMask** are combined using **&**, all the bits except the high-order (leftmost) bit in variable **value** are "masked off" (hidden), because any bit "ANDed" with **0** yields **0**. If the leftmost bit is **1**, **value & displayMask** evaluates to a nonzero value and **1** is appended; otherwise, **0** is appended. Then vari-

able **value** is left shifted one bit by the expression **value <<= 1** (this is equivalent to **value = value << 1**). These steps are repeated for each bit in variable **value**. At the end of method **getBits**, the **StringBuffer** is converted to a **String** in line 79 and returned from the method. Figure 20.7 summarizes the results of combining two bits with the bitwise AND (**&**) operator.

Common Programming Error 20.1

*Using the logical AND operator (**&&**) for the bitwise AND operator (**&**) is a common programming error.*

Figure 20.8 demonstrates the bitwise AND operator, the bitwise inclusive OR operator, the bitwise exclusive OR operator and the bitwise complement operator. The program uses method **getBits** (lines 163–188) to get a **String** representation of the integer values. The program allows the user to enter values into **JTextField**s (for the binary operators, two values must be entered), and then to press the button representing the operation they would like to test. The program displays the result of each operation in both integer and bitwise representations.

The first output window for Fig. 20.8 shows the results of combining the value **65535** and the value **1** with the bitwise AND operator (**&**). All the bits except the low-order bit in the value **65535** are "masked off" (hidden) by "ANDing" with the value **1**.

Bit 1	Bit 2	Bit 1 & Bit 2
0	0	0
1	0	0
0	1	0
1	1	1

Fig. 20.7 Results of combining two bits with the bitwise AND operator (**&**).

```
1  // Fig. 20.8: MiscBitOps.java
2  // Using the bitwise AND, bitwise inclusive OR, bitwise
3  // exclusive OR, and bitwise complement operators.
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class MiscBitOps extends JFrame {
13    private JTextField input1Field, input2Field,
14       bits1Field, bits2Field, bits3Field, resultField;
```

Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 1 of 6).

```
15    private int value1, value2;
16
17    // set up GUI
18    public MiscBitOps()
19    {
20       super( "Bitwise operators" );
21
22       JPanel inputPanel = new JPanel();
23       inputPanel.setLayout( new GridLayout( 4, 2 ) );
24
25       inputPanel.add( new JLabel( "Enter 2 ints" ) );
26       inputPanel.add( new JLabel( "" ) );
27
28       inputPanel.add( new JLabel( "Value 1" ) );
29       input1Field = new JTextField( 8 );
30       inputPanel.add( input1Field );
31
32       inputPanel.add( new JLabel( "Value 2" ) );
33       input2Field = new JTextField( 8 );
34       inputPanel.add( input2Field );
35
36       inputPanel.add( new JLabel( "Result" ) );
37       resultField = new JTextField( 8 );
38       resultField.setEditable( false );
39       inputPanel.add( resultField );
40
41       JPanel bitsPanel = new JPanel();
42       bitsPanel.setLayout( new GridLayout( 4, 1 ) );
43       bitsPanel.add( new JLabel( "Bit representations" ) );
44
45       bits1Field = new JTextField( 33 );
46       bits1Field.setEditable( false );
47       bitsPanel.add( bits1Field );
48
49       bits2Field = new JTextField( 33 );
50       bits2Field.setEditable( false );
51       bitsPanel.add( bits2Field );
52
53       bits3Field = new JTextField( 33 );
54       bits3Field.setEditable( false );
55       bitsPanel.add( bits3Field );
56
57       JPanel buttonPanel = new JPanel();
58
59       // button to perform bitwise AND
60       JButton andButton = new JButton( "AND" );
61
62       andButton.addActionListener(
63
64          new ActionListener() {
65
```

Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 2 of 6).

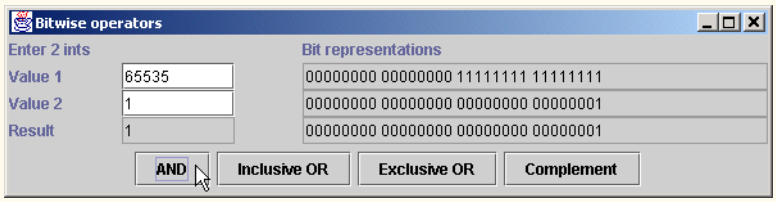
```
66              // perform bitwise AND and display results
67              public void actionPerformed( ActionEvent event )
68              {
69                 setFields();
70                 resultField.setText(
71                    Integer.toString( value1 & value2 ) );
72                 bits3Field.setText( getBits( value1 & value2 ) );
73              }
74           }
75        );
76
77        buttonPanel.add( andButton );
78
79        // button to perform bitwise inclusive OR
80        JButton inclusiveOrButton = new JButton( "Inclusive OR" );
81
82        inclusiveOrButton.addActionListener(
83
84           new ActionListener() {
85
86              // perform bitwise inclusive OR and display results
87              public void actionPerformed( ActionEvent event )
88              {
89                 setFields();
90                 resultField.setText(
91                    Integer.toString( value1 | value2 ) );
92                 bits3Field.setText( getBits( value1 | value2 ) );
93              }
94           }
95        );
96
97        buttonPanel.add( inclusiveOrButton );
98
99        // button to perform bitwise exclusive OR
100       JButton exclusiveOrButton = new JButton( "Exclusive OR" );
101
102       exclusiveOrButton.addActionListener(
103
104          new ActionListener() {
105
106             // perform bitwise exclusive OR and display results
107             public void actionPerformed( ActionEvent event )
108             {
109                setFields();
110                resultField.setText(
111                   Integer.toString( value1 ^ value2 ) );
112                bits3Field.setText( getBits( value1 ^ value2 ) );
113             }
114          }
115       );
116
117       buttonPanel.add( exclusiveOrButton );
```

Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 3 of 6).

```
118
119       // button to perform bitwise complement
120       JButton complementButton = new JButton( "Complement" );
121
122       complementButton.addActionListener(
123
124          new ActionListener() {
125
126             // perform bitwise complement and display results
127             public void actionPerformed( ActionEvent event )
128             {
129                input2Field.setText( "" );
130                bits2Field.setText( "" );
131
132                int value = Integer.parseInt( input1Field.getText() );
133
134                resultField.setText( Integer.toString( ~value ) );
135                bits1Field.setText( getBits( value ) );
136                bits3Field.setText( getBits( ~value ) );
137             }
138          }
139       );
140
141       buttonPanel.add( complementButton );
142
143       Container container = getContentPane();
144       container.add( inputPanel, BorderLayout.WEST );
145       container.add( bitsPanel, BorderLayout.EAST );
146       container.add( buttonPanel, BorderLayout.SOUTH );
147
148       setSize( 600, 150 );
149       setVisible( true );
150    }
151
152    // display numbers and their bit form
153    private void setFields()
154    {
155       value1 = Integer.parseInt( input1Field.getText() );
156       value2 = Integer.parseInt( input2Field.getText() );
157
158       bits1Field.setText( getBits( value1 ) );
159       bits2Field.setText( getBits( value2 ) );
160    }
161
162    // display bit representation of specified int value
163    private String getBits( int value )
164    {
165       // create int value with 1 in leftmost bit and 0s elsewhere
166       int displayMask = 1 << 31;
167
168       // buffer to build output
169       StringBuffer buffer = new StringBuffer( 35 );
```

Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 4 of 6).

```
170
171        // for each bit append 0 or 1 to buffer
172        for ( int bit = 1; bit <= 32; bit++ ) {
173
174           // use displayMask to isolate bit and determine whether
175           // bit has value of 0 or 1
176           buffer.append(
177              ( value & displayMask ) == 0 ? '0' : '1' );
178
179           // shift value one position to left
180           value <<= 1;
181
182           // append space to buffer every 8 bits
183           if ( bit % 8 == 0 )
184              buffer.append( ' ' );
185        }
186
187        return buffer.toString();
188     }
189
190     // execute application
191     public static void main( String args[] )
192     {
193        MiscBitOps application = new MiscBitOps();
194
195        application.setDefaultCloseOperation(
196           JFrame.EXIT_ON_CLOSE );
197     }
198
199  }  // end class MiscBitOps
```



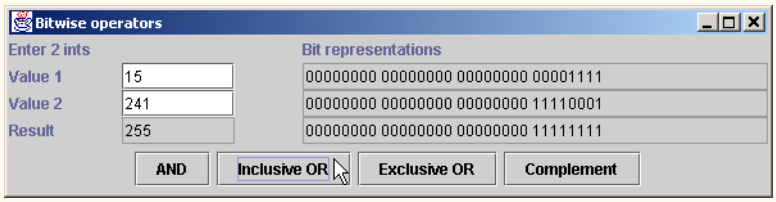


Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 5 of 6).

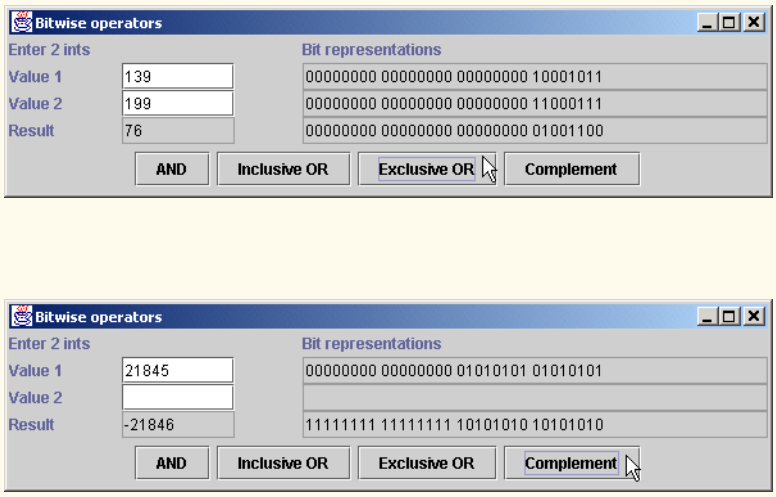


Fig. 20.8 Demonstrating the bitwise AND, bitwise inclusive OR, bitwise exclusive OR and bitwise complement operators (part 6 of 6).

The bitwise inclusive OR operator sets specific bits to 1 in an operand. The second output window for Fig. 20.8 shows the results of combining the value **15** and the value **241** by using the bitwise OR operator—the result is **255**. Figure 20.9 summarizes the results of combining two bits with the bitwise inclusive OR operator.

Common Programming Error 20.2

Using the logical OR operator (||) for the bitwise OR operator (|) is a common programming error.

The bitwise exclusive OR operator (^) sets each bit in the result to 1 if *exactly* one of the corresponding bits in its two operands is 1. The third output of Fig. 20.8 shows the results of combining the value **139** and the value **199** by using the exclusive OR operator—the result is **76**. Figure 20.10 summarizes the results of combining two bits with the bitwise exclusive OR operator.

Bit 1	Bit 2	Bit 1 | Bit 2
0	0	0
1	0	1
0	1	1
1	1	1

Fig. 20.9 Results of combining two bits with the bitwise inclusive OR operator (|).

Bit 1	Bit 2	Bit 1 ^ Bit 2
0	0	0
1	0	1
0	1	1
1	1	0

Fig. 20.10 Results of combining two bits with the bitwise exclusive OR operator (^).

The *bitwise* complement operator (**~**) sets all **1** bits in its operand to **0** in the result and sets all **0** bits to **1** in the result—otherwise referred to as "taking the *one's complement* of the value." The fourth output window for Fig. 20.8 shows the results of taking the one's complement of the value **21845**. The result is **-21846**.

The program of Fig. 20.11 demonstrates the *left shift operator* (**<<**), the *right shift operator with sign extension* (**>>**) and the *right shift operator with zero extension* (**>>>**). Method **getBits** (lines 113–138) obtains a **String** containing the bit representation of the integer values. The program allows the user to enter an integer into a **JTextField** and press *Enter* to display the bit representation of the integer in a second **JTextField**. The the user can press a button representing a shift operation to perform a 1-bit shift and view the results of the shift in both integer and bitwise representation.

```
1  // Fig. 20.11: BitShift.java
2  // Using the bitwise shift operators.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7
8  // Java extension packages
9  import javax.swing.*;
10
11 public class BitShift extends JFrame {
12    private JTextField bitsField;
13    private JTextField valueField;
14
15    // set up GUI
16    public BitShift()
17    {
18       super( "Shifting bits" );
19
20       Container container = getContentPane();
21       container.setLayout( new FlowLayout() );
22
23       container.add( new JLabel( "Integer to shift " ) );
24
25       // textfield for user to input integer
26       valueField = new JTextField( 12 );
```

Fig. 20.11 Demonstrating the bitwise shift operators (part 1 of 5).

```
27          container.add( valueField );
28
29          valueField.addActionListener(
30
31             new ActionListener() {
32
33                // read value and display its bitwise representation
34                public void actionPerformed( ActionEvent event )
35                {
36                  int value = Integer.parseInt( valueField.getText() );
37                    bitsField.setText( getBits( value ) );
38                }
39             }
40          );
41
42          // textfield to display bitwise representation of an integer
43          bitsField = new JTextField( 33 );
44          bitsField.setEditable( false );
45          container.add( bitsField );
46
47          // button to shift bits left by one position
48          JButton leftButton = new JButton( "<<" );
49
50          leftButton.addActionListener(
51
52             new ActionListener() {
53
54                // left shift one position and display new value
55                public void actionPerformed( ActionEvent event )
56                {
57                  int value = Integer.parseInt( valueField.getText() );
58                    value <<= 1;
59                    valueField.setText( Integer.toString( value ) );
60                    bitsField.setText( getBits( value ) );
61                }
62             }
63          );
64
65          container.add( leftButton );
66
67         // button to right shift value one position with sign extension
68          JButton rightSignButton = new JButton( ">>" );
69
70          rightSignButton.addActionListener(
71
72             new ActionListener() {
73
74                // right shift one position and display new value
75                public void actionPerformed( ActionEvent event )
76                {
77                  int value = Integer.parseInt( valueField.getText() );
78                    value >>= 1;
79                    valueField.setText( Integer.toString( value ) );
```

Fig. 20.11 Demonstrating the bitwise shift operators (part 2 of 5).

```
80                bitsField.setText( getBits( value ) );
81             }
82          }
83       );
84
85       container.add( rightSignButton );
86
87       // button to right shift value one position with zero extension
88       JButton rightZeroButton = new JButton( ">>>" );
89
90       rightZeroButton.addActionListener(
91
92          new ActionListener() {
93
94             // right shift one position and display new value
95             public void actionPerformed( ActionEvent event )
96             {
97               int value = Integer.parseInt( valueField.getText() );
98                value >>>= 1;
99                valueField.setText( Integer.toString( value ) );
100
101               bitsField.setText( getBits( value ) );
102            }
103         }
104      );
105
106      container.add( rightZeroButton );
107
108      setSize( 400, 120 );
109      setVisible( true );
110   }
111
112   // display bit representation of specified int value
113   private String getBits( int value )
114   {
115      // create int value with 1 in leftmost bit and 0s elsewhere
116      int displayMask = 1 << 31;
117
118      // buffer to build output
119      StringBuffer buffer = new StringBuffer( 35 );
120
121      // for each bit append 0 or 1 to buffer
122      for ( int bit = 1; bit <= 32; bit++ ) {
123
124         // use displayMask to isolate bit and determine whether
125         // bit has value of 0 or 1
126         buffer.append(
127            ( value & displayMask ) == 0 ? '0' : '1' );
128
129         // shift value one position to left
130         value <<= 1;
131
```

Fig. 20.11 Demonstrating the bitwise shift operators (part 3 of 5).

```
132           // append space to buffer every 8 bits
133           if ( bit % 8 == 0 )
134              buffer.append( ' ' );
135        }
136
137        return buffer.toString();
138     }
139
140     // execute application
141     public static void main( String args[] )
142     {
143        BitShift application = new BitShift();
144
145        application.setDefaultCloseOperation(
146           JFrame.EXIT_ON_CLOSE );
147     }
148
149  }  // end class BitShift
```

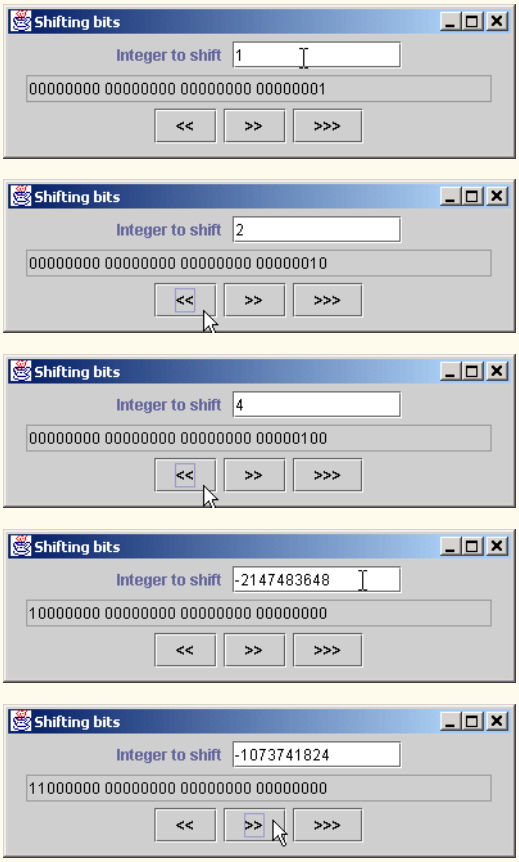


Fig. 20.11 Demonstrating the bitwise shift operators (part 4 of 5).

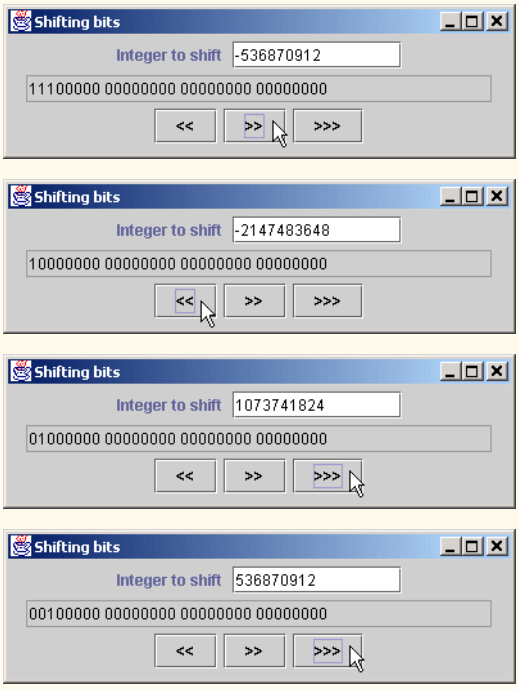


Fig. 20.11 Demonstrating the bitwise shift operators (part 5 of 5).

The left shift operator (**<<**) shifts the bits of its left operand to the left by the number of bits specified in its right operand (performed at line 58 in the program). Bits vacated to the right are replaced with **0**s; **1**s shifted off the left are lost. The first four output windows of Fig. 20.11 demonstrate the left shift operator. Starting with the value 1, the left shift button was pressed twice, resulting in the values 2 and 4, respectively. The fourth output window shows the result of **value1** being shifted 31 times. Note that the result is a negative value. That is because a 1 in the high-order bit is used to indicate a negative value in an integer.

The right shift operator with sign extension (**>>**) shifts the bits of its left operand to the right by the number of bits specified in its right operand (performed at line 78 in the program). Performing a right shift causes the vacated bits at the left to be replaced by **0**s if the number is positive or **1**s if the number is negative. Any **1**s shifted off the right are lost. The fifth and sixth output windows show the results of right shifting (with sign extension) the value in the fourth output window two times.

The right shift operator with zero extension (**>>>**) shifts the bits of its left operand to the right by the number of bits specified in its right operand (performed at line 98 in the program). Performing a right shift causes the vacated bits at the left to be replaced by **0**s. Any **1**s shifted off the right are lost. The eighth and ninth output windows show the results of right shifting (with zero extension) the value in the seventh output window two times.

Each bitwise operator (except the bitwise complement operator) has a corresponding assignment operator. These *bitwise assignment operators* are shown in Fig. 20.12.

Bitwise assignment operators	
`&=`	Bitwise AND assignment operator.
`|=`	Bitwise inclusive OR assignment operator.
`^=`	Bitwise exclusive OR assignment operator.
`<<=`	Left shift assignment operator.
`>>=`	Right shift with sign extension assignment operator.
`>>>=`	Right shift with zero extension assignment operator.

Fig. 20.12 The bitwise assignment operators.

20.9 `BitSet` Class

Class ***`BitSet`*** makes it easy to create and manipulate *bit sets*. Bit sets are useful for representing a set of **`boolean`** flags. **`BitSet`**s are dynamically resizable. More bits can be added as needed, and a **`BitSet`** object will grow to accommodate the additional bits. The statement

```
BitSet b = new BitSet();
```

creates a **`BitSet`** that initially is empty. Also, a program can specify the size of a **`BitSet`** with the statement

```
BitSet b = new BitSet( size );
```

which creates a **`BitSet`** with **`size`** bits.

The statement

```
b.set( bitNumber );
```

sets bit **`bitNumber`** "on." This makes the underlying value of that bit 1. Note that bit numbers are zero based, like **`Vector`**s. The statement

```
b.clear( bitNumber );
```

sets bit **`bitNumber`** "off." This makes the underlying value of that bit 0. The statement

```
b.get( bitNumber );
```

gets the value of bit **`bitNumber`**. The result is returned as **`true`** if the bit is on, **`false`** if the bit is off.

The statement

```
b.and( b1 );
```

performs a bit-by-bit logical AND between **`BitSet`**s **`b`** and **`b1`**. The result is stored in **`b`**. Bitwise logical OR and bitwise logical XOR are performed by the statements

```
b.or( b1 );
b.xor( b2 );
```

The expression

```
b.size()
```

returns the size of the **BitSet**. The expression

```
b.equals( b1 )
```

compares the two **BitSet**s for equality. The expression

```
b.toString()
```

creates a **String** representation of the **BitSet** contents. This is helpful for debugging.

Figure 20.13 revisits the Sieve of Eratosthenes for finding prime numbers, which we discussed in Exercise 7.27. This example uses a **BitSet** rather than an array to implement the algorithm. The program displays all the prime numbers from 2 to 1023 in a **JTextArea** and provides a **JTextField** in which the user can type any number from 2 to 1023 to determine whether that number is prime (in which case a message is displayed in a **JLabel**).

```
1  // Fig. 20.13: BitSetTest.java
2  // Using a BitSet to demonstrate the Sieve of Eratosthenes.
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.util.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class BitSetTest extends JFrame {
13    private BitSet sieve;
14    private JLabel statusLabel;
15    private JTextField inputField;
16
17    // set up GUI
18    public BitSetTest()
19    {
20       super( "BitSets" );
21
22       sieve = new BitSet( 1024 );
23
24       Container container = getContentPane();
25
26       statusLabel = new JLabel( "" );
27       container.add( statusLabel, BorderLayout.SOUTH );
28
29       JPanel inputPanel = new JPanel();
30
31       inputPanel.add( new JLabel(
32           "Enter a value from 2 to 1023" ) );
```

Fig. 20.13 Demonstrating the Sieve of Eratosthenes using a **BitSet** (part 1 of 3).

```
33
34          // textfield for user to input a value from 2 to 1023
35          inputField = new JTextField( 10 );
36
37          inputField.addActionListener(
38
39             new ActionListener() {
40
41                // determine whether value is prime number
42                public void actionPerformed( ActionEvent event )
43                {
44                  int value = Integer.parseInt( inputField.getText() );
45
46                   if ( sieve.get( value ) )
47                      statusLabel.setText(
48                         value + " is a prime number" );
49
50                   else
51                      statusLabel.setText( value +
52                         " is not a prime number" );
53                }
54             }
55          );
56
57          inputPanel.add( inputField );
58          container.add( inputPanel, BorderLayout.NORTH );
59
60          JTextArea primesArea = new JTextArea();
61
62          container.add( new JScrollPane( primesArea ),
63             BorderLayout.CENTER );
64
65          // set all bits from 1 to 1023
66          int size = sieve.size();
67
68          for ( int i = 2; i < size; i++ )
69             sieve.set( i );
70
71          // perform Sieve of Eratosthenes
72          int finalBit = ( int ) Math.sqrt( sieve.size() );
73
74          for ( int i = 2; i < finalBit; i++ )
75
76             if ( sieve.get( i ) )
77
78                for ( int j = 2 * i; j < size; j += i )
79                   sieve.clear( j );
80
81          // display prime numbers from 1 to 1023
82          int counter = 0;
83
```

Fig. 20.13 Demonstrating the Sieve of Eratosthenes using a **`BitSet`** (part 2 of 3).

```
84          for ( int i = 2; i < size; i++ )
85
86             if ( sieve.get( i ) ) {
87                primesArea.append( String.valueOf( i ) );
88                primesArea.append( ++counter % 7 == 0 ? "\n" : "\t" );
89             }
90
91          setSize( 600, 450 );
92          setVisible( true );
93       }
94
95       // execute application
96       public static void main( String args[] )
97       {
98          BitSetTest application = new BitSetTest();
99
100         application.setDefaultCloseOperation(
101            JFrame.EXIT_ON_CLOSE );
102      }
103
104   }  // end class BitSetTest
```

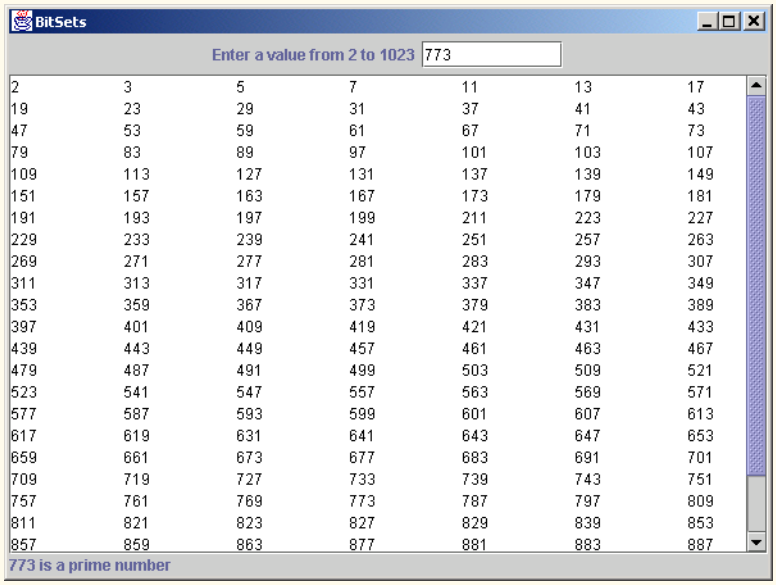


Fig. 20.13 Demonstrating the Sieve of Eratosthenes using a **`BitSet`** (part 3 of 3).

Line 22 creates a **`BitSet`** of 1024 bits. We ignore the bit at index 0 in this program. Lines 68–69 set all the bits in the **`BitSet`** to on with **`BitSet`** method **`set`**. Lines 72–79 determine all the prime numbers from 2 to 1023. The integer **`finalBit`** specifies when the algorithm is complete. The basic algorithm is that a number is prime if it has no divisors other than 1 and itself. Starting with the number 2, once we know a number is prime, we can eliminate all multiples of that number. The number 2 is only divisible by 1 and itself, so it is prime. Therefore, we can eliminate 4, 6, 8 and so on. Elimination of a value consists

of setting its bit to off with **BitSet** method **clear**. The number 3 is divisible by 1 and itself. Therefore, we can eliminate all multiples of 3 (keep in mind that all even numbers have already been eliminated). After the list of primes is displayed, the user can type a value from 2 to 1023 in the textfield and press enter to determine whether the number is prime. Method **actionPerformed** (lines 42–53) uses **BitSet** method **get** (line 46) to determine whether the bit for the number the user entered is set. If so, lines 47–48 display a message indicating that the number is prime. Otherwise, lines 51–52 display a message indicating that the number is not prime.

SUMMARY

- Class **Vector** manages dynamically resizable arrays. At any time the **Vector** contains a certain number of elements which is less than or equal to its capacity. The capacity is the space that has been reserved for the array.
- If a **Vector** needs to grow, it grows by an increment that you specify or by a default assumed by the system. If you do not specify a capacity increment, the system automatically doubles the size of the **Vector** each time additional capacity is required.
- **Vector**s store references to **Object**s. To store values of primitive data types in **Vector**s, use the type-wrapper classes (**Byte**, **Short**, **Integer**, **Long**, **Float**, **Double**, **Boolean** and **Character**) to create objects containing the primitive data type values.
- Class **Vector** provides three constructors. The no-argument constructor creates an empty **Vector**. The constructor that takes one argument creates a **Vector** with an initial capacity specified by the argument. The constructor that takes two arguments creates a **Vector** with an initial capacity specified by the first argument and a capacity increment specified by the second argument.
- **Vector** method **addElement** adds its argument to the end of the **Vector**. Method **insertElementAt** inserts an element at the specified position. Method **setElementAt** sets the element at a specific position.
- **Vector** method **removeElement** removes the first occurrence of its argument. Method **removeAllElements** removes every element from the **Vector**. Method **removeElementAt** removes the element at the specified index.
- **Vector** method **firstElement** returns a reference to the first element. Method **lastElement** returns a reference to the last element.
- **Vector** method **isEmpty** determines whether the **Vector** is empty.
- **Vector** method **contains** determines whether the **Vector** contains the **searchKey** specified as an argument.
- **Vector** method **indexOf** gets the index of the first location of its argument. The method returns **-1** if the argument is not found in the **Vector**.
- **Vector** method **trimToSize** cuts the capacity of the **Vector** to the **Vector**'s size. Methods **size** and **capacity** determine the number of elements currently in the **Vector** and the number of elements that can be stored in the **Vector** without allocating more memory, respectively.
- **Vector** method **elements** returns a reference to an **Enumeration** containing the elements of the **Vector**.
- **Enumeration** method **hasMoreElements** determines whether there are more elements. Method **nextElement** returns a reference to the next element.
- Class **Stack** extends class **Vector**. **Stack** method **push** adds its argument to the top of the stack. Method **pop** removes the top element of the stack. Method **peek** returns an **Object** ref-

erence to the top element of the stack without removing the element. **`Stack`** method **`empty`** determines whether the stack is empty.

- A **`Dictionary`** transforms keys to values.
- Hashing is a high-speed scheme for converting keys into unique array subscripts for storage and retrieval of information.The load factor is the ratio of the number of occupied cells in a hash table to the size of the hash table. The closer this ratio gets to 1.0, the greater the chance of collisions.
- The no-argument **`Hashtable`** constructor creates a **`Hashtable`** with a default capacity of 101 elements and a default load factor of .75. The **`Hashtable`** constructor that takes one argument specifies the initial capacity; the constructor that takes two arguments specifies the initial capacity and load factor, respectively.
- **`Hashtable`** method **`put`** adds a key and a value into a **`Hashtable`**. Method **`get`** locates the value associated with the specified key. Method **`remove`** deletes the value associated with the specified key. Method **`isEmpty`** determines whether the table is empty.
- **`Hashtable`** method **`containsKey`** determines whether the key specified as an argument is in the **`Hashtable`** (i.e., a value is associated with that key). Method **`contains`** determines whether the **`Object`** specified as its argument is in the **`Hashtable`**. Method **`clear`** empties the **`Hashtable`**. Method **`elements`** obtains an **`Enumeration`** of the values. Method **`keys`** obtains an **`Enumeration`** of the keys.
- A **`Properties`** object is a persistent **`Hashtable`** object. Class **`Properties`** extends **`Hashtable`**. Keys and values in a **`Properties`** object must be **`String`**s.
- The **`Properties`** no-argument constructor creates an empty **`Properties`** table with no default properties. There is also an overloaded constructor that is passed a reference to a default **`Properties`** object containing default property values.
- **`Properties`** method **`getProperty`** locates the value of the key specified as an argument. Method **`store`** saves the contents of the **`Properties`** object to the **`OutputStream`** object specified as the first argument. Method **`load`** restores the contents of the **`Properties`** object from the **`InputStream`** object specified as the argument. Method **`propertyNames`** obtains an **`Enumeration`** of the property names.
- Java provides extensive random-number generation capabilities in class **`Random`**. Class **`Random`**'s no-argument constructor uses the time to seed its random-number generator differently each time it is called. To create a pseudorandom-number generator with repeatability, use the **`Random`** constructor that takes a seed argument.
- **`Random`** method **`setSeed`** sets the seed. Methods **`nextInt`** and **`nextLong`** generate uniformly distributed random integers. Methods **`nextFloat`** and **`nextDouble`** generate uniformly distributed values in the range $0.0 <= x < 1.0$.
- The bitwise AND (**`&`**) operator sets each bit in the result to 1 if the corresponding bit in both operands is 1.
- The bitwise inclusive OR (**`|`**) operator sets each bit in the result to 1 if the corresponding bit in either (or both) operand(s) is 1.
- The bitwise exclusive OR (**`^`**) operator sets each bit in the result to 1 if the corresponding bit in exactly one operand is 1.
- The left shift (**`<<`**) operator shifts the bits of its left operand to the left by the number of bits specified in its right operand.
- The right shift operator with sign extension (**`>>`**) shifts the bits in its left operand to the right by the number of bits specified in its right operand—if the left operand is negative, **`1`**s are shifted in from the left; otherwise, **`0`**s are shifted in from the left.

- The right shift operator with zero extension (**>>>**) shifts the bits in its left operand to the right by the number of bits specified in its right operand—**0**s are shifted in from the left.
- The bitwise complement (**~**) operator sets all **0** bits in its operand to **1** in the result and sets all **1** bits to **0** in the result.
- Each bitwise operator (except complement) has a corresponding assignment operator.
- The no-argument **BitSet** constructor creates an empty **BitSet**. The one-argument **BitSet** constructor creates a **BitSet** with the number of bits specified by its argument.
- **BitSet** method **set** sets the specified bit "on." Method **clear** sets the specified bit "off." Method **get** returns **true** if the bit is on, **false** if the bit is off.
- **BitSet** method **and** performs a bit-by-bit logical AND between **BitSet**s. The result is stored in the **BitSet** that invoked the method. Similarly, bitwise logical OR and bitwise logical XOR are performed by methods **or** and **xor**.
- **BitSet** method **size** returns the size of a **BitSet**. Method **toString** converts a **BitSet** to a **String**.

TERMINOLOGY

addElement method of class **Vector**
and method of class **BitSet**
bit set
BitSet class
bitwise assignment operators
  &= (bitwise AND)
  ^= (bitwise exclusive OR)
  |= (bitwise inclusive OR)
  <<= (left shift)
  >>= (right shift)
  >>>= (right shift with zero extension)
bitwise manipulation operators
  & bitwise AND
  ^ bitwise exclusive OR
  | bitwise inclusive OR
  ~ one's complement
  << left shift
  >> right shift
  >>> right shift with zero extension
capacity increment of a **Vector**
capacity method of class **Vector**
capacity of a **Vector**
clear method of class **BitSet**
clear method of class **Hashtable**
clone method of class **BitSet**
collision in hashing
contains method of class **Vector**
containsKey method of class **Hashtable**
defaults
Dictionary class
dynamically resizable array
elementAt method of class **Vector**
elements method of class **Dictionary**
elements method of class **Vector**
EmptyStackException class
enumerate successive elements
Enumeration interface
equals method of class **Object**
firstElement method of class **Vector**
get method of class **BitSet**
get method of class **Dictionary**
getProperty method of class **Properties**
hashCode method of class **Object**
hashing
Hashtable class
hasMoreElements method (**Enumeration**)
indexOf method of class **Vector**
initial capacity of a **Vector**
insertElementAt method of class **Vector**
isEmpty method of class **Dictionary**
isEmpty method of class **Vector**
iterate through container elements
java.util package
key in a **Dictionary**
key/value pair
keys method of class **Dictionary**
lastElement method of class **Vector**
list method of class **Properties**
load factor in hashing
load method of class **Properties**
nextDouble method of class **Random**
nextElement method of **Enumeration**
nextFloat method of class **Random**
nextInt method of class **Random**

nextLong method of class **Random**
NoSuchElementException class
NullPointerException
or method of class **BitSet**
peek method of class **Stack**
persistent hash table
pop method of class **Stack**
Properties class
propertyNames method of **Properties**
pseudorandom numbers
push method of class **Stack**
put method of class **Dictionary**
Random class
remove method of class **Dictionary**
removeAllElements method of **Vector**
removeElement method of class **Vector**
removeElementAt method of class **Vector**
search method of class **Stack**
seed of a random-number generator
set method of class **BitSet**
setElementAt method of class **Vector**
setSeed method of class **Random**
setSize method of class **Vector**
size method of class **Dictionary**
size method of class **Vector**
Stack class
store method of class **Properties**
trimToSize method of class **Vector**
Vector class
white-space characters
xor method of class **BitSet**

SELF-REVIEW EXERCISES

20.1 Fill in the blanks in each of the following statements:
a) Java class _____ provides the capabilities of array-like data structures that can resize themselves dynamically.
b) If you do not specify a capacity increment, the system will _____ the size of the **Vector** each time additional capacity is needed.
c) If storage is at a premium, use the _____ method of the **Vector** class to trim a **Vector** to its exact size.

20.2 State whether each of the following is *true* or *false*. If *false*, explain why.
a) Values of primitive data types may be stored directly in a **Vector**.
b) With hashing, as the load factor increases, the chance of collisions decreases.

20.3 Under what circumstances is an **EmptyStackException** thrown?

20.4 Fill in the blanks in each of the following statements:
a) Bits in the result of an expression using operator _____ are set to 1 if the corresponding bits in each operand are set to 1. Otherwise, the bits are set to zero.
b) Bits in the result of an expression using operator _____ are set to 1 if at least one of the corresponding bits in either operand is set to 1. Otherwise, the bits are set to zero.
c) Bits in the result of an expression using operator _____ are set to 1 if exactly one of the corresponding bits in either operand is set to 1. Otherwise, the bits are set to zero.
d) The bitwise AND operator (**&**) is often used to _____ bits, that is, to select certain bits from a bit string while zeroing others.
e) The _____ operator is used to shift the bits of a value to the left.
f) The _____ operator shifts the bits of a value to the right with sign extension, and the _____ operator shifts the bits of a value to the right with zero extension.

ANSWERS TO SELF-REVIEW EXERCISES

20.1 a) **Vector**. b) double. c) **trimToSize**.

20.2 a) False; a **Vector** stores only **Object**s. A program must use the type-wrapper classes (**Byte**, **Short**, **Integer**, **Long**, **Float**, **Double**, **Boolean** and **Character**) from package **java.lang** to create **Object**s containing the primitive data type values. b) False; as the load fac-

tor increases, there are fewer available slots relative to the total number of slots, so the chance of selecting an occupied slot (a collision) with a hashing operation increases.

20.3 When a program calls **`pop`** or **`peek`** on an empty **`Stack`** object, an **`EmptyStackException`** occurs.

20.4 a) bitwise AND (**`&`**). b) bitwise inclusive OR (**`|`**). c) bitwise exclusive OR (**`^`**). d) mask. e) left shift operator (**`<<`**). f) right shift operator with sign extension (**`>>`**), right shift operator with zero extension (**`>>>`**).

EXERCISES

20.5 Define each of the following terms in the context of hashing:
a) key
b) collision
c) hashing transformation
d) load factor
e) space–time trade-off
f) **`Hashtable`** class
g) capacity of a **`Hashtable`**

20.6 Explain briefly the operation of each of the following methods of class **`Vector`**:
a) **`addElement`**
b) **`insertElementAt`**
c) **`setElementAt`**
d) **`removeElement`**
e) **`removeAllElements`**
f) **`removeElementAt`**
g) **`firstElement`**
h) **`lastElement`**
i) **`isEmpty`**
j) **`contains`**
k) **`indexOf`**
l) **`trimToSize`**
m) **`size`**
n) **`capacity`**

20.7 Explain why inserting additional elements into a **`Vector`** object whose current size is less than its capacity is a relatively fast operation and why inserting additional elements into a **`Vector`** object whose current size is at capacity is a relatively slow operation.

20.8 In the text, we state that the default capacity increment of doubling the size of a **`Vector`** might seem wasteful of storage, but it is actually an efficient way for **`Vector`**s to grow quickly to be "about the right size." Explain this statement. Explain the pros and cons of this doubling algorithm. What can a program do when it determines that the doubling is wasting space?

20.9 Explain the use of the **`Enumeration`** interface with objects of class **`Vector`**.

20.10 By extending class **`Vector`**, Java's designers were able to create class **`Stack`** quickly. What are the negative aspects of this use of inheritance, particularly for class **`Stack`**?

20.11 Explain briefly the operation of each of the following methods of class **`Hashtable`**:
a) **`put`**
b) **`get`**
c) **`remove`**
d) **`isEmpty`**

e) **containsKey**
f) **contains**
g) **clear**
h) **elements**
i) **keys**

20.12 Explain how to use the **Random** class to create pseudorandom numbers with the repeatability required for debugging purposes.

20.13 Use a **Hashtable** to create a reusable class for choosing one of the 13 predefined colors in class **Color**. The name of the color should be used as keys and the predefined **Color** objects should be used as values. Place this class in a package that can be imported into any Java program. Use your new class in an application that allows the user to select a color and draw a shape in that color.

20.14 Modify your solution to Exercise 13.18—the polymorphic painting program—to store every shape the user draws in a **Vector** of **MyShape** objects. For the purpose of this exercise, create your own **Vector** subclass called **ShapeVector** that manipulates only **MyShape** objects. Provide the following capabilities in your program:

a) Allow the user of the program to remove any number of shapes from the **Vector** by clicking an **Undo** button.
b) Allow the user to select any shape on the screen and move it to a new location. This requires the addition of a new method to the **MyShape** hierarchy. The method's first line should be

```
public boolean isInside()
```

This method should be overridden for each subclass of **MyShape** to determine whether the coordinates where the user pressed the mouse button are inside the shape.
c) Allow the user to select any shape on the screen and change its color.
d) Allow the user to select any shape on the screen that can be filled or unfilled and change its fill state.

20.15 What does it mean when we state that a **Properties** object is a "persistent" **Hashtable** object? Explain the operation of each of the following methods of the **Properties** class:

a) **load**
b) **store**
c) **getProperty**
d) **propertyNames**
e) **list**

20.16 Why might you want to use objects of class **BitSet**? Explain the operation of each of the following methods of class **BitSet**:

a) **set**
b) **clear**
c) **get**
d) **and**
e) **or**
f) **xor**
g) **size**
h) **equals**
i) **clone**
j) **toString**
k) **hashCode**

20.17 Write a program that right shifts an integer variable 4 bits with sign extension and then right shifts the same integer variable 4 bits with zero extension. The program should print the integer in

bits before and after each shift operation. Run your program once with a positive integer and once with a negative integer.

20.18 Show how shifting an integer left by 1 can be used to simulate multiplication by 2 and how shifting an integer right by 2 can be used to simulate division by 2. Be careful to consider issues related to the sign of an integer.

20.19 Write a program that reverses the order of the bits in an integer value. The program should input the value from the user and call method **`reverseBits`** to print the bits in reverse order. Print the value in bits both before and after the bits are reversed to confirm that the bits are reversed properly. You might want to implement both a recursive and an iterative solution.

20.20 Modify your solution to Exercise 19.10 to use class **`Stack`**.

20.21 Modify your solution to Exercise 19.12 to use class **`Stack`**.

20.22 Modify your solution to Exercise 19.13 to use class **`Stack`**.

21

Collections

Objectives

- To understand what collections are.
- To understand Java 2's new array capabilities.
- To use the collections framework implementations.
- To be able to use collections framework algorithms to manipulate various collections.
- To be able to use the collections framework interfaces to program polymorphically.
- To be able to use iterators to walk through the elements of a collection.
- To understand synchronization wrappers and modifiability wrappers.

I think this is the most extraordinary collection of talent, of human knowledge, that has ever been gathered together at the White House—with the possible exception of when Thomas Jefferson dines alone.
John F. Kennedy

The shapes a bright container can contain!
Theodore Roethke

Journey over all the universe in a map.
Miguel de Cervantes

It is an immutable law in business that words are words, explanations are explanations, promises are promises — but only performance is reality.
Harold S. Green

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Outline

21.1 Introduction
21.2 Collections Overview
21.3 Class `Arrays`
21.4 Interface `Collection` and Class `Collections`
21.5 Lists
21.6 Algorithms
21.6.1 Algorithm `sort`
21.6.2 Algorithm `shuffle`
21.6.3 Algorithms `reverse`, `fill`, `copy`, `max` and `min`
21.6.4 Algorithm `binarySearch`
21.7 Sets
21.8 Maps
21.9 Synchronization Wrappers
21.10 Unmodifiable Wrappers
21.11 Abstract Implementations
21.12 (Optional) Discovering Design Patterns: Design Patterns Used in Package `java.util`

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

21.1 Introduction

In Chapter 19, we discussed how to create and manipulate data structures. The discussion was "low level," in the sense that we painstakingly created each element of each data structure dynamically with **`new`** and modified the data structures by directly manipulating their elements and references to their elements. In this chapter, we consider the Java collections framework, which gives the programmer access to prepackaged data structures, as well as algorithms for manipulating those data structures.

With collections, instead of creating data structures, the programmer simply uses existing data structures, without concern for how the data structures are implemented. This methodology is a marvelous example of code reuse. Programmers can code faster and can expect excellent performance, maximizing execution speed and minimizing memory consumption. We will discuss the interfaces of the collections framework, the implementation classes, the algorithms that process them and the *iterators* that "walk" through them.

Some examples of collections are the cards you hold in a card game, your favorite songs stored in your computer and the real-estate records in your local registry of deeds (which map book numbers and page numbers to property owners). Java 2 provides an entire collections framework, whereas earlier versions of Java provided just a few collection classes, such as **`Hashtable`**, **`Stack`** and **`Vector`** (see Chapter 20), as well as built-in array capabilities. If you know C++, you will be familiar with its collections framework,

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which is called the Standard Template Library (STL). (See Chapter 20 of *C++ How to Program, Third Edition*, by H. M. Deitel and P. J. Deitel, ©2001, Prentice Hall).

The Java collections framework provides ready-to-go, reusable componentry; you do not need to write your own collection classes. The collections are standardized so applications can share them easily, without having to be concerned with the details of their implementation. These collections are written for broad reuse. They are tuned for rapid execution as well as efficient use of memory. The collections framework encourages further reusability. As new data structures and algorithms are developed that fit this framework, a large base of programmers already will be familiar with the interfaces and algorithms implemented by those data structures.

21.2 Collections Overview

A collection is a data structure—actually, an object—that can hold other objects. The collection interfaces define the operations that a program can perform on each type of collection. The collection implementations execute the operations in particular ways, some more appropriate than others for specific kinds of applications. Thecollection implementations are carefully constructed for rapid execution and efficient use of memory. Collections encourage software reuse by providing convenient functionality.

The collections framework provides interfaces that define the operations to be performed generically on various types of collections. Some of the interfaces are **`Collection`**, **`Set`**, **`List`** and **`Map`**. Several implementations of these interfaces are provided within the framework. Programmers may also provide implementations specific to their own requirements.

The collections framework includes a number of other features that minimize the amount of coding programmers need to do to create and manipulate collections.

The classes and interfaces that comprise the collections framework are members of package **`java.util`**. In the next section, we begin our discussion by examining the capabilities that have been added for array manipulation.

21.3 Class `Arrays`

We begin our discussion of the collections framework by looking at class ***`Arrays`***, which provides **`static`** methods for manipulating arrays. In Chapter 7, our discussion of array manipulation was "low level," in the sense that we wrote the actual code to sort and search arrays. Class **`Arrays`** provides "high-level" methods, such as ***`binarySearch`*** for searching a sorted array, ***`equals`*** for comparing arrays, ***`fill`*** for placing values into an array and ***`sort`*** for sorting an array. These methods are overloaded for primitive-type arrays and **`Object`** arrays. Figure 21.1 demonstrates the use of these methods.

```
1  // Fig. 21.1: UsingArrays.java
2  // Using Java arrays.
3
4  // Java core packages
5  import java.util.*;
```

Fig. 21.1 Using methods of class **`Arrays`** (part 1 of 3).

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```
 6
 7  public class UsingArrays {
 8     private int intValues[] = { 1, 2, 3, 4, 5, 6 };
 9     private double doubleValues[] = { 8.4, 9.3, 0.2, 7.9, 3.4 };
10     private int filledInt[], intValuesCopy[];
11
12     // initialize arrays
13     public UsingArrays()
14     {
15        filledInt = new int[ 10 ];
16        intValuesCopy = new int[ intValues.length ];
17
18        Arrays.fill( filledInt, 7 );    // fill with 7s
19
20        Arrays.sort( doubleValues );    // sort doubleValues
21
22        System.arraycopy( intValues, 0, intValuesCopy,
23           0, intValues.length );
24     }
25
26     // output values in each array
27     public void printArrays()
28     {
29        System.out.print( "doubleValues: " );
30
31        for ( int count = 0; count < doubleValues.length; count++ )
32           System.out.print( doubleValues[ count ] + " " );
33
34        System.out.print( "\nintValues: " );
35
36        for ( int count = 0; count < intValues.length; count++ )
37           System.out.print( intValues[ count ] + " " );
38
39        System.out.print( "\nfilledInt: " );
40
41        for ( int count = 0; count < filledInt.length; count++ )
42           System.out.print( filledInt[ count ] + " " );
43
44        System.out.print( "\nintValuesCopy: " );
45
46        for ( int count = 0; count < intValuesCopy.length; count++ )
47           System.out.print( intValuesCopy[ count ] + " " );
48
49        System.out.println();
50     }
51
52     // find value in array intValues
53     public int searchForInt( int value )
54     {
55        return Arrays.binarySearch( intValues, value );
56     }
57
```

Fig. 21.1 Using methods of class **Arrays** (part 2 of 3).

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```
58      // compare array contents
59      public void printEquality()
60      {
61         boolean b = Arrays.equals( intValues, intValuesCopy );
62
63         System.out.println( "intValues " + ( b ? "==" : "!=" )
64                             + " intValuesCopy" );
65
66         b = Arrays.equals( intValues, filledInt );
67
68         System.out.println( "intValues " + ( b ? "==" : "!=" )
69                             + " filledInt" );
70      }
71
72      // execute application
73      public static void main( String args[] )
74      {
75         UsingArrays usingArrays = new UsingArrays();
76
77         usingArrays.printArrays();
78         usingArrays.printEquality();
79
80         int location = usingArrays.searchForInt( 5 );
81         System.out.println( ( location >= 0 ?
82            "Found 5 at element " + location : "5 not found" ) +
83            " in intValues" );
84
85         location = usingArrays.searchForInt( 8763 );
86         System.out.println( ( location >= 0 ?
87            "Found 8763 at element " + location :
88            "8763 not found" ) + " in intValues" );
89      }
90
91   }  // end class UsingArrays
```

```
doubleValues: 0.2 3.4 7.9 8.4 9.3
intValues: 1 2 3 4 5 6
filledInt: 7 7 7 7 7 7 7 7 7 7
intValuesCopy: 1 2 3 4 5 6
intValues == intValuesCopy
intValues != filledInt
Found 5 at element 4 in intValues
8763 not found in intValues
```

Fig. 21.1 Using methods of class **Arrays** (part 3 of 3).

Line 18 calls **Arrays** **static** method **fill** to populate all 10 elements of array **filledInt** with **7**s. Overloaded versions of **fill** allow the programmer to populate a specific range of elements with the same value.

Line 20 sorts the elements of array **doubleValues**. Overloaded versions of **sort** allow the programmer to sort a specific range of elements. **Arrays** **static** method **sort** orders the array's elements in ascending order by default. We discuss how to sort in descending order later in the chapter.

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Lines 22–23 copy array **intValues** into array **intValuesCopy**. The first argument (**intValues**) passed to **System static** method ***arraycopy*** is the array from which elements are copied. The second argument (**0**) is the array (i.e., **intValues**) subscript that specifies the starting point in the range of elements to copy. This value can be any valid array subscript. The third argument (**intValuesCopy**) specifies the array that stores the copy. The fourth argument (**0**) specifies the subscript in the destination array (i.e., **intValuesCopy**) where the first copied element is stored. The last argument (**intValues.length**) specifies the number of source-array (i.e., **intValues**) elements to copy.

Line 55 calls **Arrays static** method **binarySearch** to perform a binary search on **intValues**, using **value** as the key. If **value** is found, **binarySearch** returns the subscript location where **value** was found. If **value** is not found, **binarySearch** returns a negative value. The negative value returned is based on the search key's *insertion point*—the index where the key would be inserted in the binary search tree if this were an insert operation. After **binarySearch** determines the insertion point, it changes the insertion point's sign to negative and subtracts **1** to obtain the return value. For example, in Fig. 21.1, the insertion point for the value **8763** is the element with subscript **6** in the array. Method **binarySearch** changes the insertion point to **-6** and subtracts **1** from it, then returns the value **-7**. This return value is useful for adding elements to a sorted array.

Common Programming Error 21.1

*Passing an unsorted array to **binarySearch** is a logic error. The value returned by **binarySearch** is undefined.*

Lines 61 and 66 call method **equals** to determine whether the elements of two arrays are equivalent. If they are equal, method **equals** returns **true**; otherwise, it returns **false**.

One of the most important features of the collection framework is the ability to manipulate the elements of one collection type through a different collection type, regardless of the collection's internal implementation. The **public** set of methods through which collections are manipulated is called a *view*.

Class **Arrays** provides **static** method ***asList*** for viewing an array as a ***List*** collection type (a type that encapsulates behavior similar to that of the linked lists created in Chapter 19; we will say more about **List**s later in the chapter). A **List** view allows the programmer to manipulate the array programmatically as if it were a **List** by calling **List** methods. Any modifications made through the **List** view change the array, and any modifications made to the array change the **List** view. Figure 21.2 demonstrates method **asList**.

```
1  // Fig. 21.2: UsingAsList.java
2  // Using method asList
3
4  // Java core packages
5  import java.util.*;
6
7  public class UsingAsList {
8     private String values[] = { "red", "white", "blue" };
9     private List list;
10
```

Fig. 21.2 Using **static** method **asList** (part 1 of 2).

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```
11      // initialize List and set value at location 1
12      public UsingAsList()
13      {
14         list = Arrays.asList( values );    // get List
15         list.set( 1, "green" );            // change a value
16      }
17
18      // output List and array
19      public void printElements()
20      {
21         System.out.print( "List elements : " );
22
23         for ( int count = 0; count < list.size(); count++ )
24            System.out.print( list.get( count ) + " " );
25
26         System.out.print( "\nArray elements: " );
27
28         for ( int count = 0; count < values.length; count++ )
29            System.out.print( values[ count ] + " " );
30
31         System.out.println();
32      }
33
34      // execute application
35      public static void main( String args[] )
36      {
37         new UsingAsList().printElements();
38      }
39
40   }  // end class UsingAsList
```

```
List elements : red green blue
Array elements: red green blue
```

Fig. 21.2 Using **`static`** method **`asList`** (part 2 of 2).

Line 9 declares a **`List`** reference called **`list`**. Line 14 uses **`static Arrays`** method **`asList`** to obtain a fixed-size **`List`** view of array **`values`**.

Performance Tip 21.1

`Arrays.asList` *creates a fixed-size* ***`List`*** *that operates faster than any of the provided* ***`List`*** *implementations.*

Common Programming Error 21.2

A ***`List`*** *created with* ***`Arrays.asList`*** *is fixed in size; calling methods* ***`add`*** *or* ***`remove`*** *throws an* ***`UnsupportedOperationException`***.

Line 15 calls **`List`** method ***`set`*** to change the contents of **`List`** element **`1`** to **`"green"`**. Because the program views the array as a **`List`**, line 15 changes array element **`values[ 1 ]`** from **`"white"`** to **`"green"`**. Any changes made to the **`List`** view are made to the underlying array object.

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Software Engineering Observation 21.1

With the collections framework, there are many methods that apply to **`List`***s and* **`Collection`***s that you would like to be able to use for arrays.* **`Arrays.asList`** *allows you to pass an array into a* **`List`** *or* **`Collection`** *parameter.*

Line 23 calls **`List`** method ***`size`*** to get the number of items in the **`List`**. Line 24 calls **`List`** method ***`get`*** to retrieve an individual item from the **`List`**. Notice that the value returned by **`size`** is equal to the number of elements in array **`values`** and that the items returned by **`get`** are the elements of array **`values`**.

21.4 Interface `Collection` and Class `Collections`

Interface ***`Collection`*** is the root interface in the collections hierarchy from which interfaces **`Set`** (a collection that does not contain duplicates—discussed in Section 21.7) and **`List`** are derived. Interface **`Collection`** contains *bulk operations* (i.e., operations performed on the entire collection) for adding, clearing, comparing and retaining objects (also called *elements*) in the collection. **`Collection`**s can also be converted to arrays. In addition, interface **`Collection`** provides a method that returns an ***`Iterator`***. **`Iterator`**s are similar to the **`Enumeration`**s introduced in Chapter 20. The primary difference between an **`Iterator`** and an **`Enumeration`** is that **`Iterator`**s can remove elements from a collection, whereas **`Enumeration`**s cannot. Other methods of interface **`Collection`** enable a program to determine a collection's size, a collection's hash code and whether a collection is empty.

Software Engineering Observation 21.2

`Collection` *is used commonly as a method parameter type to allow polymorphic processing of all objects that implement interface* ***`Collection`***.

Software Engineering Observation 21.3

Most collection implementations provide a constructor that takes a **`Collection`** *argument, thereby allowing one collection type to be treated as another collection type.*

Class ***`Collections`*** provides **`static`** methods that manipulate collections polymorphically. These methods implement algorithms for searching, sorting, and so on. You will learn more about these algorithms in Section 21.6. Other **`Collections`** methods include *wrapper methods* that return new collections. We discuss wrapper methods in Section 21.9 and Section 21.10.

21.5 Lists

A **`List`** is an ordered **`Collection`** that can contain duplicate elements. A **`List`** is sometimes called a *sequence*. Like arrays, **`List`**s are zero based (i.e., the first element's *index* is zero). In addition to the interface methods inherited from **`Collection`**, **`List`** provides methods for manipulating elements via their indices, manipulating a specified range of elements, searching the elements and getting a ***`ListIterator`*** to access the elements.

Interface **`List`** is implemented by classes ***`ArrayList`***, ***`LinkedList`*** and **`Vector`**. Class **`ArrayList`** is a resizable-array implementation of a **`List`**. Class **`ArrayList`**'s behavior and capabilities are similar to those of the **`Vector`** class, introduced in Chapter 20. A **`LinkedList`** is a linked-list implementation of a **`List`**.

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Performance Tip 21.2

`ArrayList`s behave like un`synchronized` `Vector`s and therefore execute faster than `Vector`s, because `ArrayList`s are not thread safe.

Software Engineering Observation 21.4

`LinkedList`s can be used to create stacks, queues, trees and deques (double-ended queues).

Figure 21.3 uses an **`ArrayList`** to demonstrate some of the capabilities of **`Collection`** interfaces. The program places **`String`**s and **`Color`**s in an **`ArrayList`** and uses an **`Iterator`** to remove the **`String`**s from the **`ArrayList`** collection.

```
1  // Fig. 21.3: CollectionTest.java
2  // Using the Collection interface
3
4  // Java core packages
5  import java.awt.Color;
6  import java.util.*;
7
8  public class CollectionTest {
9     private String colors[] = { "red", "white", "blue" };
10
11    // create ArrayList, add objects to it and manipulate it
12    public CollectionTest()
13    {
14       ArrayList list = new ArrayList();
15
16       // add objects to list
17       list.add( Color.magenta );      // add a color object
18
19       for ( int count = 0; count < colors.length; count++ )
20          list.add( colors[ count ] );
21
22       list.add( Color.cyan );         // add a color object
23
24       // output list contents
25       System.out.println( "\nArrayList: " );
26
27       for ( int count = 0; count < list.size(); count++ )
28          System.out.print( list.get( count ) + " " );
29
30       // remove all String objects
31       removeStrings( list );
32
33       // output list contents
34       System.out.println( "\n\nArrayList after calling" +
35          " removeStrings: " );
36
37       for ( int count = 0; count < list.size(); count++ )
38          System.out.print( list.get( count ) + " " );
39    }
```

Fig. 21.3 Using an **`ArrayList`** to demonstrate interface **`Collection`** (part 1 of 2).

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```
40
41     // remove String objects from Collection
42     public void removeStrings( Collection collection )
43     {
44        // get iterator
45        Iterator iterator = collection.iterator();
46
47        // loop while collection has items
48        while ( iterator.hasNext() )
49
50           if ( iterator.next() instanceof String )
51              iterator.remove();  // remove String object
52     }
53
54     // execute application
55     public static void main( String args[] )
56     {
57        new CollectionTest();
58     }
59
60  }  // end class CollectionTest
```

```
ArrayList:
java.awt.Color[r=255,g=0,b=255] red white blue java.awt.Color
[r=0,g=255,b=255]

ArrayList after calling removeStrings:
java.awt.Color[r=255,g=0,b=255] java.awt.Color[r=0,g=255,b=255]
```

Fig. 21.3 Using an **ArrayList** to demonstrate interface **Collection** (part 2 of 2).

Line 14 creates reference **list** and initializes it with an instance of an **ArrayList**. Lines 17–22 populate **list** with **Color** and **String** objects. Lines 25–28 output each element of **list**. Line 27 calls **List** method ***size*** to get the number of **ArrayList** elements. Line 28 uses **List** method ***get*** to retrieve individual element values. Line 31 calls programmer-defined method **removeStrings** (defined on lines 42–52), passing **list** to it as an argument. Method **removeStrings** deletes **String**s from a collection. Lines 34–38 print the elements of **list** after **removeStrings** removes the **String** objects from the list. Notice that the output in Fig. 21.3 contains only **Color**s.

Method **removeStrings** declares one parameter of type **Collection** that allows any **Collection** to be passed as an argument to this method. The method accesses the elements of the **Collection** via an **Iterator**. Line 45 calls method ***iterator*** to get an **Iterator** for the **Collection**. The **while** loop condition on line 48 calls **Iterator** method ***hasNext*** to determine if the **Collection** contains any more elements. Method **hasNext** returns **true** if another element exists and **false** otherwise.

The **if** condition at line 50 calls **Iterator** method ***next*** to obtain a reference to the next element, then uses **instanceof** to determine whether the object is a **String**. If so, line 51 calls **Iterator** method ***remove*** to remove the **String** from the **Collection**.

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Common Programming Error 21.3

When iterating through a collection with an **`Iterator`**, *use* **`Iterator`** *method* **`remove`** *to delete an element from the collection. Using the collection's* **`remove`** *method will result in a* **`ConcurrentModificationException`**.

Figure 21.4 demonstrates operations on **`LinkedList`**s. The program creates two **`LinkedList`**s that each contain **`String`**s. The elements of one **`List`** are added to the other. Then, all the **`String`**s are converted to uppercase, and a range of elements is deleted.

```
1  // Fig. 21.4: ListTest.java
2  // Using LinkLists
3
4  // Java core packages
5  import java.util.*;
6
7  public class ListTest {
8     private String colors[] = { "black", "yellow", "green",
9        "blue", "violet", "silver" };
10    private String colors2[] = { "gold", "white", "brown",
11       "blue", "gray", "silver" };
12
13    // set up and manipulate LinkedList objects
14    public ListTest()
15    {
16       LinkedList link = new LinkedList();
17       LinkedList link2 = new LinkedList();
18
19       // add elements to each list
20       for ( int count = 0; count < colors.length; count++ ) {
21          link.add( colors[ count ] );
22          link2.add( colors2[ count ] );
23       }
24
25       link.addAll( link2 );           // concatenate lists
26       link2 = null;                   // release resources
27
28       printList( link );
29
30       uppercaseStrings( link );
31
32       printList( link );
33
34       System.out.print( "\nDeleting elements 4 to 6..." );
35       removeItems( link, 4, 7 );
36
37       printList( link );
38    }
39
40    // output List contents
41    public void printList( List list )
42    {
43       System.out.println( "\nlist: " );
```

Fig. 21.4 Using **`List`**s and **`ListIterator`**s (part 1 of 2).

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```
44
45          for ( int count = 0; count < list.size(); count++ )
46             System.out.print( list.get( count ) + " " );
47
48          System.out.println();
49       }
50
51       // locate String objects and convert to uppercase
52       public void uppercaseStrings( List list )
53       {
54          ListIterator iterator = list.listIterator();
55
56          while ( iterator.hasNext() ) {
57             Object object = iterator.next();  // get item
58
59             if ( object instanceof String )   // check for String
60                iterator.set(
61                   ( ( String ) object ).toUpperCase() );
62          }
63       }
64
65       // obtain sublist and use clear method to delete sublist items
66       public void removeItems( List list, int start, int end )
67       {
68          list.subList( start, end ).clear();  // remove items
69       }
70
71       // execute application
72       public static void main( String args[] )
73       {
74          new ListTest();
75       }
76
77    }  // end class ListTest
```

```
list:
black yellow green blue violet silver gold white brown blue gray silver

list:
BLACK YELLOW GREEN BLUE VIOLET SILVER GOLD WHITE BROWN BLUE GRAY SILVER

Deleting elements 4 to 6...
list:
BLACK YELLOW GREEN BLUE WHITE BROWN BLUE GRAY SILVER
```

Fig. 21.4 Using **List**s and **ListIterator**s (part 2 of 2).

Lines 16–17 create **LinkedList**s **link** and **link2**, respectively. Lines 20–23 call method **add** to append elements from arrays **colors** and **colors2** to the end of **LinkedList**s **link** and **link2**, respectively.

Line 25 calls method ***addAll*** to append all elements of **link2** to the end of **link**. Line 26 sets **link2** to **null**, so **LinkedList** can be garbage collected. Line 28 calls programmer-defined method **printList** (lines 41–49) to output the **link**'s contents.

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Line 30 calls programmer-defined method **uppercaseStrings** (lines 52–63) to convert the **String** elements to uppercase; then line 32 calls **printList** to display the modified **String**s. Line 34 calls programmer-defined method **removeItems** (lines 66–69) to remove the elements at positions 4 through 6 of the list.

Method **uppercaseStrings** (lines 52–63) changes lowercase **String** elements in the **List** passed to it to uppercase **String**s. Line 54 calls method ***listIterator*** to get a *bidirectional iterator* (i.e., an iterator that can traverse a **List** backward or forward) for the **List**. The **while** condition calls method **hasNext** to determine whether the **List** contains another element. Line 57 gets the next **Object** from the **List** and assigns it to **object**. The **if** condition tests **object** to determine whether it is an **instanceof** class **String**. If so, lines 60–61 cast **object** to a **String**, call method **toUpperCase** to get an uppercase version of the **String** and call method ***set*** to replace the current **String** to which **iterator** refers with the **String** returned by method **toUpperCase**.

Programmer-defined method **removeItems** (lines 66–69) removes a range of items from the list. Line 68 calls method ***subList*** to obtain a portion of the **List** called a *sublist*. The sublist is simply a view into the **List** on which **subList** is called. Method **subList** takes two arguments—the beginning index for the sublist and the ending index for the sublist. Note that the ending index is not part of the range of the sublist. In this example, we pass **4** for the beginning index and **7** for the ending index to **subList**. The sublist returned is the elements with indices **4** through **6**. Next, the program calls method ***clear*** on the sublist to remove the elements of the sublist from the **List**. Any changes made to a sublist are made to the original **List**.

Figure 21.5 uses method ***toArray*** to get an array from a collection (i.e., **LinkedList**). The program adds a series of **String**s to a **LinkedList** and calls method **toArray** to get an array from the **LinkedList**.

```
1  // Fig. 21.5: UsingToArray.java
2  // Using method toArray
3
4  // Java core packages
5  import java.util.*;
6
7  public class UsingToArray {
8
9     // create LinkedList, add elements and convert to array
10    public UsingToArray()
11    {
12       LinkedList links;
13       String colors[] = { "black", "blue", "yellow" };
14
15       links = new LinkedList( Arrays.asList( colors ) );
16
17       links.addLast( "red" );    // add as last item
18       links.add( "pink" );       // add to the end
19       links.add( 3, "green" );   // add at 3rd index
20       links.addFirst( "cyan" ); // add as first item
21
```

Fig. 21.5 Using method **toArray** (part 1 of 2).

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```
22         // get LinkedList elements as an array
23         colors = ( String [] ) links.toArray(
24            new String[ links.size() ] );
25
26         System.out.println( "colors: " );
27
28         for ( int count = 0; count < colors.length; count++ )
29            System.out.println( colors[ count ] );
30      }
31
32      // execute application
33      public static void main( String args[] )
34      {
35         new UsingToArray();
36      }
37
38   }  // end class UsingToArray
```

```
colors:
cyan
black
blue
yellow
green
red
pink
```

Fig. 21.5 Using method **toArray** (part 2 of 2).

Line 15 constructs a **LinkedList** containing the elements of array **colors** and assigns the **LinkedList** to **links**. Line 17 calls method ***addLast*** to add **"red"** to the end of **links**. Lines 18–19 call method ***add*** to add **"pink"** as the last element and **"green"** as the element at index **3** (i.e., the fourth element). Line 20 calls ***addFirst*** to add **"cyan"** as the new first item in the **LinkedList**. [*Note*: When **"cyan"** is added as the first element, **"green"** becomes the fifith element in the **LinkedList**.]

Lines 23–24 call method **toArray** to get a **String** array from **links**. The array is a copy of the list elements—modifying the contents of the array does not modify the **LinkedList**. The array passed to method **toArray** is of the same data type as that returned by **toArray**. If the number of elements in the array is greater than the number of elements in the **LinkedList**, **toArray** copies the list elements into its array argument and returns that array. If the **LinkedList** has more elements than the number of elements in the array passed to **toArray**, **toArray** allocates a new array of the same type it receives as an argument, copies the list elements into the new array and returns the new array.

Common Programming Error 21.4

Passing an array that contains data to ***toArray*** *can create logic errors. If the number of elements in the array is smaller than the number of elements in the* ***Object*** *calling* ***toArray****, new memory is allocated to store the* ***Object****'s elements—without preserving the array's elements. If the number of elements in the array is greater than the number of elements in the* ***Object****, the elements of the array (starting at subscript* ***0****) are overwritten with the* ***Object****'s elements. Array elements that are not overwritten retain their values.*

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21.6 Algorithms

The collections framework provides a variety of high-performance algorithms for manipulating collection elements. These algorithms are implemented as **`static`** methods. Algorithms ***`sort`***, ***`binarySearch`***, ***`reverse`***, ***`shuffle`***, ***`fill`*** and ***`copy`*** operate on **`List`**s. Algorithms ***`min`*** and ***`max`*** operate on **`Collection`**s.

Algorithm ***`reverse`*** reverses the elements of a **`List`**, ***`fill`*** sets every **`List`** element to refer to a specified **`Object`** and **`copy`** copies references from one **`List`** into another.

Software Engineering Observation 21.5

The collections framework algorithms are polymorphic. That is, each algorithm can operate on objects that offer given interfaces without concern to the underlying implementations.

21.6.1 Algorithm `sort`

Algorithm ***`sort`*** sorts the elements of a **`List`**. The order is determined by the natural order of the elements' type. The **`sort`** call may specify as a second argument a ***`Comparator`*** object that specifies how to determine the ordering of the elements.

Algorithm **`sort`** uses a *stable sort* (i.e., a sort that does not reorder equivalent elements while sorting). The **`sort`** algorithm is fast. For readers who have studied some complexity theory in data structures or algorithms courses, this sort runs in $n \log(n)$ time. (Readers not familiar with complexity theory, may rest assured that this algorithm is extremely fast .

Software Engineering Observation 21.6

The Java API documentation sometimes provides implementation details. For example, ***`sort`*** *is implemented as a modified merge sort. Avoid writing code that is dependent on implementation details, because they can change.*

Figure 21.6 uses algorithm **`sort`** to order the elements of an **`ArrayList`** into ascending order (line 21).

```
1  // Fig. 21.6: Sort1.java
2  // Using algorithm sort
3
4  // Java core packages
5  import java.util.*;
6
7  public class Sort1 {
8     private static String suits[] =
9        { "Hearts", "Diamonds", "Clubs", "Spades" };
10
11    // display array elements
12    public void printElements()
13    {
14       // create ArrayList
15       ArrayList list = new ArrayList( Arrays.asList( suits ) );
16
17       // output list
18       System.out.println( "Unsorted array elements:\n" + list );
```

Fig. 21.6 Using algorithm **`sort`** (part 1 of 2).

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```
19
20          // sort ArrayList
21          Collections.sort( list );
22
23          // output list
24          System.out.println( "Sorted array elements:\n" + list );
25       }
26
27       // execute application
28       public static void main( String args[] )
29       {
30          new Sort1().printElements();
31       }
32
33    }  // end class Sort1
```

```
Unsorted array elements:
[Hearts, Diamonds, Clubs, Spades]
Sorted array elements:
[Clubs, Diamonds, Hearts, Spades]
```

Fig. 21.6 Using algorithm **sort** (part 2 of 2).

Figure 21.7 sorts the same **String**s used in Fig. 21.6 into descending order. The example introduces the **Comparator** object, for sorting a **Collection**'s elements in a different order.

```
1  // Fig. 21.7: Sort2.java
2  // Using a Comparator object with algorithm sort
3
4  // Java core packages
5  import java.util.*;
6
7  public class Sort2 {
8     private static String suits[] =
9        { "Hearts", "Diamonds", "Clubs", "Spades" };
10
11    // output List elements
12    public void printElements()
13    {
14       // create List
15       List list = Arrays.asList( suits );
16
17       // output List elements
18       System.out.println( "Unsorted array elements:\n" + list );
19
20       // sort in descending order using a comparator
21       Collections.sort( list, Collections.reverseOrder() );
22
```

Fig. 21.7 Using a **Comparator** object in **sort** (part 1 of 2).

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```
23         // output List elements
24         System.out.println( "Sorted list elements:\n" + list );
25      }
26
27      // execute application
28      public static void main( String args[] )
29      {
30         new Sort2().printElements();
31      }
32
33   }  // end class Sort2
```

```
Unsorted array elements:
[Hearts, Diamonds, Clubs, Spades]
Sorted list elements:
[Spades, Hearts, Diamonds, Clubs]
```

Fig. 21.7 Using a **Comparator** object in **sort** (part 2 of 2).

Line 21 calls **Collections**'s method **sort** to order the **List** view of the array into descending order. The **static Collections** method ***reverseOrder*** returns a **Comparator** object that represents the collection's reverse order. For sorting a **List** view of a **String** array, the reverse order is a *lexicographical comparison*—the comparator compares the Unicode values that represent each element—in descending order.

21.6.2 Algorithm shuffle

Algorithm **shuffle** randomly orders a **List**'s elements. In Chapter 10, we presented a card shuffling and dealing simulation where we used a loop to shuffle a deck of cards. In Fig. 21.8, we use algorithm **shuffle** to shuffle the deck of cards. Much of the code is the same as in Fig. 10.19. The shuffling of the deck occurs on line 63, which calls **static Collections** method **shuffle** to shuffle the array through the array's **List** view.

```
1  // Fig. 21.8: Cards.java
2  // Using algorithm shuffle
3
4  // Java core packages
5  import java.util.*;
6
7  // class to represent a Card in a deck of cards
8  class Card {
9     private String face;
10    private String suit;
11
12    // initialize a Card
13    public Card( String initialface, String initialSuit )
14    {
15       face = initialface;
16       suit = initialSuit;
17    }
```

Fig. 21.8 Card shuffling and dealing example (part 1 of 3).

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```
18
19     // return face of Card
20     public String getFace()
21     {
22        return face;
23     }
24
25     // return suit of Card
26     public String getSuit()
27     {
28        return suit;
29     }
30
31     // return String representation of Card
32     public String toString()
33     {
34        StringBuffer buffer =
35           new StringBuffer( face + " of " + suit );
36
37        buffer.setLength( 20 );
38
39        return buffer.toString();
40     }
41
42  }  // end class Card
43
44  // class Cards definition
45  public class Cards {
46     private static String suits[] =
47        { "Hearts", "Clubs", "Diamonds", "Spades" };
48     private static String faces[] = { "Ace", "Deuce", "Three",
49        "Four", "Five", "Six", "Seven", "Eight", "Nine", "Ten",
50        "Jack", "Queen", "King" };
51     private List list;
52
53     // set up deck of Cards and shuffle
54     public Cards()
55     {
56        Card deck[] = new Card[ 52 ];
57
58        for ( int count = 0; count < deck.length; count++ )
59           deck[ count ] = new Card( faces[ count % 13 ],
60              suits[ count / 13 ] );
61
62        list = Arrays.asList( deck );    // get List
63        Collections.shuffle( list );     // shuffle deck
64     }
65
66     // output deck
67     public void printCards()
68     {
69        int half = list.size() / 2 - 1;
70
```

Fig. 21.8 Card shuffling and dealing example (part 2 of 3).

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```
71         for ( int i = 0, j = half; i <= half; i++, j++ )
72            System.out.println(
73               list.get( i ).toString() + list.get( j ) );
74      }
75
76      // execute application
77      public static void main( String args[] )
78      {
79         new Cards().printCards();
80      }
81
82   }  // end class Cards
```

```
King of Diamonds    Ten of Spades
Deuce of Hearts     Five of Spades
King of Clubs       Five of Clubs
Jack of Diamonds    Jack of Spades
King of Spades      Ten of Clubs
Six of Clubs        Three of Clubs
Seven of Clubs      Jack of Clubs
Seven of Hearts     Six of Spades
Eight of Hearts     Six of Diamonds
King of Hearts      Nine of Diamonds
Ace of Hearts       Four of Hearts
Jack of Hearts      Queen of Diamonds
Queen of Clubs      Six of Hearts
Seven of Diamonds   Ace of Spades
Three of Spades     Deuce of Spades
Seven of Spades     Five of Diamonds
Ten of Hearts       Queen of Hearts
Ten of Diamonds     Eight of Clubs
Nine of Spades      Three of Diamonds
Four of Spades      Ace of Clubs
Four of Clubs       Four of Diamonds
Nine of Clubs       Three of Hearts
Eight of Diamonds   Deuce of Diamonds
Deuce of Clubs      Nine of Hearts
Eight of Spades     Five of Hearts
Ten of Spades       Queen of Spades
```

Fig. 21.8 Card shuffling and dealing example (part 3 of 3).

21.6.3 Algorithms `reverse`, `fill`, `copy`, `max` and `min`

Class **`Collections`** provides algorithms for reversing, filling and copying **`List`**s. Algorithm **`reverse`** reverses the order of the elements in a **`List`**, and algorithm **`fill`** overwrites elements in a **`List`** with a specified value. The **`fill`** operation is useful for reinitializing a **`List`**. Algorithm **`copy`** takes two arguments: A destination **`List`** and a source **`List`**. Each source **`List`** element is copied to the destination **`List`**. The destination **`List`** must be at least as long as the source **`List`**: otherwise, an **`IndexOutOfBoundsException`** is thrown. If the destination **`List`** is longer, the elements not overwritten are unchanged.

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Each of the algorithms we have seen so far operates on **List**s. Algorithms **min** and **max** each operate on **Collection**s.

Algorithm **min** returns the smallest element in a **List** (remember a **List** is a **Collection**) and algorithm **max** returns the largest element in a **List**. Both of these algorithms can be called with a **Comparator** object as a second argument. Figure 21.9 demonstrates the use of algorithms **reverse**, **fill**, **copy**, **min** and **max**.

```
1  // Fig. 21.9: Algorithms1.java
2  // Using algorithms reverse, fill, copy, min and max
3
4  // Java core packages
5  import java.util.*;
6
7  public class Algorithms1 {
8     private String letters[] = { "P", "C", "M" }, lettersCopy[];
9     private List list, copyList;
10
11    // create a List and manipulate it with algorithms from
12    // class Collections
13    public Algorithms1()
14    {
15       list = Arrays.asList( letters );     // get List
16       lettersCopy = new String[ 3 ];
17       copyList = Arrays.asList( lettersCopy );
18
19       System.out.println( "Printing initial statistics: " );
20       printStatistics( list );
21
22       Collections.reverse( list );         // reverse order
23       System.out.println( "\nPrinting statistics after " +
24          "calling reverse: " );
25       printStatistics( list );
26
27       Collections.copy( copyList, list );  // copy List
28       System.out.println( "\nPrinting statistics after " +
29          "copying: " );
30       printStatistics( copyList );
31
32       System.out.println( "\nPrinting statistics after " +
33          "calling fill: " );
34       Collections.fill( list, "R" );
35       printStatistics( list );
36    }
37
38    // output List information
39    private void printStatistics( List listRef )
40    {
41       System.out.print( "The list is: " );
42
43       for ( int k = 0; k < listRef.size(); k++ )
44          System.out.print( listRef.get( k ) + " " );
45
```

Fig. 21.9 Using algorithms **reverse**, **fill**, **copy**, **max** and **min** (part 1 of 2).

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```
46          System.out.print( "\nMax: " + Collections.max( listRef ) );
47          System.out.println(
48             "  Min: " + Collections.min( listRef ) );
49       }
50
51       // execute application
52       public static void main( String args[] )
53       {
54          new Algorithms1();
55       }
56
57    }  // end class Algorithms1
```

```
Printing initial statistics:
The list is: P C M
Max: P  Min: C
Printing statistics after calling reverse:
The list is: M C P
Max: P  Min: C
Printing statistics after copying:
The list is: M C P
Max: P  Min: C
Printing statistics after calling fill:
The list is: R R R
Max: R  Min: R
```

Fig. 21.9 Using algorithms **reverse**, **fill**, **copy**, **max** and **min** (part 2 of 2).

Line 22 calls **Collections** method ***reverse*** to reverse the order of **list**. Method **reverse** takes one **List** argument. (**list** is a **List** view of **String** array **letters**.) Array **letters** now has its elements in reverse order.

Line 27 copies the elements of **list** into **copyList** with **Collections** method **copy**. Changes to **copyList** do not change **letters**—this is a separate **List** that is not a **List** view for **letters**. Method **copy** requires two **List** arguments.

Line 34 calls **Collections** method **fill** to place the **String "R"** in each element of **list**. Because **list** is a **List** view of **letters**, this operation changes each element in **letters** to **"R"**. Method **fill** requires a **List** for the first argument and an **Object** for the second argument.

Lines 46 and 48, call **Collection** methods **max** and **min** to find the largest element and the smallest element, respectively, in **list**.

21.6.4 Algorithm binarySearch

Earlier in this text, we studied the high-speed binary search algorithm. This algorithm is built right into the Java collections framework. The **binarySearch** algorithm locates an **Object** in a **List** (i.e., **LinkedList**, **Vector** or **ArrayList**) If the **Object** is found, the index (position relative to 0) of that **Object** is returned. If the **Object** is not found, **binarySearch** returns a negative value. Algorithm **binarySearch** determines this negative value by first calculating the insertion point and changing the insertion point's sign to negative. Finally, **binarySearch** subtracts one from the insertion point to obtain the return value.

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Figure 21.10 uses the **binarySearch** algorithm to search for a series of **String**s in an **ArrayList**.

```
1  // Fig. 21.10: BinarySearchTest.java
2  // Using algorithm binarySearch
3
4  // Java core packages
5  import java.util.*;
6
7  public class BinarySearchTest {
8     private String colors[] = { "red", "white", "blue", "black",
9        "yellow", "purple", "tan", "pink" };
10    private ArrayList list;         // ArrayList reference
11
12    // create, sort and output list
13    public BinarySearchTest()
14    {
15       list = new ArrayList( Arrays.asList( colors ) );
16       Collections.sort( list );    // sort the ArrayList
17       System.out.println( "Sorted ArrayList: " + list );
18    }
19
20    // search list for various values
21    public void printSearchResults()
22    {
23       printSearchResultsHelper( colors[ 3 ] ); // first item
24       printSearchResultsHelper( colors[ 0 ] ); // middle item
25       printSearchResultsHelper( colors[ 7 ] ); // last item
26       printSearchResultsHelper( "aardvark" );  // below lowest
27       printSearchResultsHelper( "goat" );      // does not exist
28       printSearchResultsHelper( "zebra" );     // does not exist
29    }
30
31    // helper method to perform searches
32    private void printSearchResultsHelper( String key )
33    {
34       int result = 0;
35
36       System.out.println( "\nSearching for: " + key );
37       result = Collections.binarySearch( list, key );
38       System.out.println(
39          ( result >= 0 ? "Found at index " + result :
40          "Not Found (" + result + ")" ) );
41    }
42
43    // execute application
44    public static void main( String args[] )
45    {
46       new BinarySearchTest().printSearchResults();
47    }
48
49 }  // end class BinarySearchTest
```

Fig. 21.10 Using algorithm **binarySearch** (part 1 of 2).

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```
Sorted ArrayList: black blue pink purple red tan white yellow
Searching for: black
Found at index 0

Searching for: red
Found at index 4

Searching for: pink
Found at index 2

Searching for: aardvark
Not Found (-1)

Searching for: goat
Not Found (-3)

Searching for: zebra
Not Found (-9)
```

Fig. 21.10 Using algorithm **binarySearch** (part 2 of 2).

Line 16 calls **Collections** method **sort** to sort **list** into ascending order. Line 37 calls **Collections** method **binarySearch** to search **list** for the specified **key**. Method **binarySearch** takes a **List** as the first argument and an **Object** as the second argument. An overloaded version of **binarySearch** takes a **Comparator** object as its third argument, to specify how **binarySearch** should compare elements.

If the search key is found, method **binarySearch** returns the **List** index of the element containing the search key. When a search key is found in the **List**, the value returned by **binarySearch** is greater than or equal to zero. If the search key is not found, method **binarySearch** returns a negative number.

Software Engineering Observation 21.7

*Java does not guarantee which item will be found first when a **binarySearch** is performed on a **List** containing multiple elements equivalent to the search key.*

21.7 Sets

A ***Set*** is a **Collection** that contains unique elements (i.e., no duplicate elements). The collections framework contains two **Set** implementations: —***HashSet*** and ***TreeSet***. **HashSet** stores its elements in a hash table, and **TreeSet** stores its elements in a tree. Figure 21.11 uses a **HashSet** to remove duplicate **String**s from an **ArrayList**.

Programmer-defined method **printNonDuplicates** (lines 23–35) takes a **Collection** argument. Line 26 constructs a **HashSet** from the **Collection** received as an argument to **printNonDuplicates**. When the **HashSet** is constructed, it removes any duplicates in the **Collection**. By definition, **Set**s do not contain any duplicates. Line 27 gets an **Iterator** for the **HashSet**. The **while** loop (lines 31–32) calls **Iterator** methods **hasNext** and **next** to access the **HashSet** elements.

Interface ***SortedSet*** extends **Set** and maintains its elements in sorted order (i.e., the elements' natural order or an order specified by a **Comparator**). Class **TreeSet** implements **SortedSet**.

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```
1  // Fig. 21.11: SetTest.java
2  // Using a HashSet to remove duplicates
3
4  // Java core packages
5  import java.util.*;
6
7  public class SetTest {
8     private String colors[] = { "red", "white", "blue",
9        "green", "gray", "orange", "tan", "white", "cyan",
10       "peach", "gray", "orange" };
11
12    // create and output ArrayList
13    public SetTest()
14    {
15       ArrayList list;
16
17       list = new ArrayList( Arrays.asList( colors ) );
18       System.out.println( "ArrayList: " + list );
19       printNonDuplicates( list );
20    }
21
22    // create set from array to eliminate duplicates
23    public void printNonDuplicates( Collection collection )
24    {
25       // create a HashSet and obtain its iterator
26       HashSet set = new HashSet( collection );
27       Iterator iterator = set.iterator();
28
29       System.out.println( "\nNonduplicates are: " );
30
31       while ( iterator.hasNext() )
32          System.out.print( iterator.next() + " " );
33
34       System.out.println();
35    }
36
37    // execute application
38    public static void main( String args[] )
39    {
40       new SetTest();
41    }
42
43 }  // end class SetTest
```

```
ArrayList: [red, white, blue, green, gray, orange, tan, white, cyan,
peach, gray, orange]

Nonduplicates are:
orange cyan green tan white blue peach red gray
```

Fig. 21.11 Using a **HashSet** to remove duplicates.

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The program of Fig. 21.12 places **`String`**s into a **`TreeSet`**. The **`String`**s are sorted automatically when they are added to the **`TreeSet`**. Also, *range-view methods* (i.e., methods that enable a program to view a portion of a collection) are demonstrated in this example.

```
1  // Fig. 21.12: SortedSetTest.java
2  // Using TreeSet and SortedSet
3
4  // Java core packages
5  import java.util.*;
6
7  public class SortedSetTest {
8     private static String names[] = { "yellow", "green", "black",
9        "tan", "grey", "white", "orange", "red", "green" };
10
11    // create a sorted set with TreeSet, then manipulate it
12    public SortedSetTest()
13    {
14       TreeSet tree = new TreeSet( Arrays.asList( names ) );
15
16       System.out.println( "set: " );
17       printSet( tree );
18
19       // get headSet based upon "orange"
20       System.out.print( "\nheadSet (\"orange\"):   " );
21       printSet( tree.headSet( "orange" ) );
22
23       // get tailSet based upon "orange"
24       System.out.print( "tailSet (\"orange\"):   " );
25       printSet( tree.tailSet( "orange" ) );
26
27       // get first and last elements
28       System.out.println( "first: " + tree.first() );
29       System.out.println( "last : " + tree.last() );
30    }
31
32    // output set
33    public void printSet( SortedSet set )
34    {
35       Iterator iterator = set.iterator();
36
37       while ( iterator.hasNext() )
38          System.out.print( iterator.next() + " " );
39
40       System.out.println();
41    }
42
43    // execute application
44    public static void main( String args[] )
45    {
46       new SortedSetTest();
47    }
```

Fig. 21.12 Using **`SortedSet`**s and **`TreeSet`**s.

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```
48
49  }  // end class SortedSetTest
```

```
set:
black green grey orange red tan white yellow

headSet ("orange"):  black green grey
tailSet ("orange"):  orange red tan white yellow
first: black
last : yellow
```

Fig. 21.12 Using **SortedSet**s and **TreeSet**s.

Line 14 constructs a **TreeSet** object containing the elements of **names** and assigns a reference to this object to **tree**. Line 21 calls method ***headSet*** to get a subset of the **TreeSet** less than **"orange"**. Any changes made to the subset are made to the **TreeSet** (i.e., the subset returned is a view of the **TreeSet**). Line 25 calls method ***tailSet*** to get a subset greater than or equal to **"orange"**. Like **headSet**, any changes made through the **tailSet** view are made to the **TreeSet**. Lines 28–29 call methods ***first*** and ***last*** to get the smallest and largest elements, respectively.

Programmer-defined method **printSet** (lines 33–41) takes a **SortedSet** (e.g., a **TreeSet**) as an argument and prints it. Line 35 gets an **Iterator** for the **Set**. The body of the **while** loop prints each element of the **SortedSet**.

21.8 Maps

Map*s* associate keys to values and cannot contain duplicate keys (i.e., each key can map to only one value; this type of mapping is called *one-to-one mapping*). **Map**s differ from **Set**s in that **Map**s contain keys and values, whereas **Set**s contain only keys. Classes ***HashMap*** and ***TreeMap*** implement the **Map** interface. **HashMap**s store elements in **HashTable**s, and **TreeMap**s store elements in trees. Interface ***SortedMap*** extends **Map** and maintains its keys in sorted order (i.e., the elements' natural order or an order, specified by a **Comparator**). Class **TreeMap** implements **SortedMap**.

Figure 21.13 uses a **HashMap** to count the number of **String**s that begin with a given letter. [Note: Unlike class **Hashtable**, class **HashMap** allows a **null** key and **null** values].

```
1  // Fig. 21.13: MapTest.java
2  // Using a HashMap to store the number of words that
3  // begin with a given letter
4
5  // Java core packages
6  import java.util.*;
7
8  public class MapTest {
9     private static String names[] = { "one", "two", "three",
10       "four", "five", "six", "seven", "two", "ten", "four" };
```

Fig. 21.13 Using **HashMap**s and **Map**s (part 1 of 2).

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```
11
12    // build a HashMap and output contents
13    public MapTest()
14    {
15       HashMap map = new HashMap();
16       Integer i;
17
18       for ( int count = 0; count < names.length; count++ ) {
19          i = ( Integer ) map.get(
20             new Character( names[ count ].charAt( 0 ) ) );
21
22          // if key is not in map then give it value one
23          // otherwise increment its value by 1
24          if ( i == null )
25             map.put(
26                new Character( names[ count ].charAt( 0 ) ),
27                new Integer( 1 ) );
28          else
29             map.put(
30                new Character( names[ count ].charAt( 0 ) ),
31                new Integer( i.intValue() + 1 ) );
32       }
33
34       System.out.println(
35          "\nnumber of words beginning with each letter:    " );
36       printMap( map );
37    }
38
39    // output map contents
40    public void printMap( Map mapRef )
41    {
42       System.out.println( mapRef.toString() );
43       System.out.println( "size: " + mapRef.size() );
44       System.out.println( "isEmpty: " + mapRef.isEmpty() );
45    }
46
47    // execute application
48    public static void main( String args[] )
49    {
50       new MapTest();
51    }
52
53 }  // end class MapTest
```

```
number of words beginning with each letter:
{t=4, s=2, o=1, f=3}
size: 4
isEmpty: false
```

Fig. 21.13 Using **HashMap**s and **Map**s (part 2 of 2).

Line 15 constructs **HashMap** **map**. The **for** loop on lines 18–32 uses **map** to store the number of words in array **names** that begin with a given letter. Lines 19–20 call method ***get*** to retrieve a **Character** (the first letter of a **String** in **names**) from the

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HashMap. If the **HashMap** does not contain a mapping for the **Character**, **get** returns **null**. If the **HashMap** does contain the mapping for the **Character**, its mapping value is returned as an **Object**. The returned value is cast to **Integer** and assigned to **i**.

If **i** is **null**, the **Character** is not in the **HashMap**, and lines 25–27 call method ***put*** to write an **Integer** containing **1** to the **HashMap**. The **Integer** value stored in the **HashMap** is the number of words beginning with that **Character**.

If the **Character** is in the **HashMap**, lines 29–31 increment the **Integer** counter by one and write the updated counter to the **HashMap**. A **HashMap** cannot contain duplicates, so **put** replaces the previous **Integer** object with the new one.

Programmer-defined method **printMap** takes one **Map** argument and prints it, using method **toString**. Lines 43–44 call methods ***size*** and ***isEmpty*** to get the number of values in the **Map** and a **boolean** indicating whether the **Map** is empty, respectively.

21.9 Synchronization Wrappers

In Chapter 15, we discussed multithreading. The built-in collections are unsynchronized. Concurrent access to a **Collection** by multiple threads could cause indeterminate results or fatal errors. To prevent potential threading problems, synchronization wrappers are used around collection classes that might be accessed by multiple threads. A *wrapper class* receives method calls, adds some functionality for thread safety and delegates the calls to the wrapped class.

The **Collections** API provides a set of **public static** methods for converting collections to synchronized versions. Method headers for the synchronization wrappers are listed in Fig. 21.14.

21.10 Unmodifiable Wrappers

The **Collections** API provides a set of **public static** methods for converting collections to unmodifiable versions (called *unmodifiable wrappers*) of those collections. Method headers for these methods are listed in Fig. 21.15. Unmodifiable wrappers throw **UnsupportedOperationException**s if attempts are made to modify the collection.

Software Engineering Observation 21.8

When creating an unmodifiable wrapper, not holding a reference to the backing collection ensures nonmodifiability.

public static method header
Collection synchronizedCollection(Collection c)
List synchronizedList(List aList)
Set synchronizedSet(Set s)
SortedSet synchronizedSortedSet(SortedSet s)
Map synchronizedMap(Map m)
SortedMap synchronizedSortedMap(SortedMap m)

Fig. 21.14 Synchronization wrapper methods.

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`public static` method header
`Collection unmodifiableCollection( Collection c )`
`List unmodifiableList( List aList )`
`Set unmodifiableSet( Set s )`
`SortedSet unmodifiableSortedSet( SortedSet s )`
`Map unmodifiableMap( Map m )`
`SortedMap unmodifiableSortedMap( SortedMap m )`

Fig. 21.15 Unmodifiable wrapper methods.

Software Engineering Observation 21.9

You can use an unmodifiable wrapper to create a collection that offers read-only access to others, while allowing read–write access to yourself. You do this simply by giving others a reference to the unmodifiable wrapper while you also retain a reference to the wrapped collection itself.

21.11 Abstract Implementations

The collections framework provides various abstract implementations (i.e., "bare bones" implementations of collection interfaces from which the programmer can quickly "flesh out" complete customized implementations). These abstract implementations are a thin **`Collection`** implementation called an ***`AbstractCollection`***, a thin **`List`** implementation with random-access backing called an ***`AbstractList`***, a thin **`Map`** implementation called an ***`AbstractMap`***, a thin **`List`** implementation with sequential-access backing called an ***`AbstractSequentialList`*** and a thin **`Set`** implementation called an ***`AbstractSet`***.

To write a custom implementation, begin by selecting as a base the abstract-implementation class that best meets your needs. Next, implement each of the class's **`abstract`** methods. Then, if your collection is to be modifiable, override any concrete methods that prevent modification.

21.12 (Optional) Discovering Design Patterns: Design Patterns Used in Package `java.util`

In this section, we use the material on data structures and collections discussed in Chapters 19, 20 and 21 to identify classes from package **`java.util`** that use design patterns. This section concludes our treatment of design patterns.

21.12.1 Creational Design Patterns

We conclude the discussion of creational design patterns by discussing the Prototype design pattern.

Prototype

Sometimes, a system must make a copy of an object but will not know that object's class until run time. For example, consider the drawing program design of Exercise 9.28—class-

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es **MyLine**, **MyOval** and **MyRect** represent "shape" classes that extend abstract superclass **MyShape**. We could modify this exercise to allow the user to create, copy and paste new instances of class **MyLine** into the program. The *Prototype design pattern* allows an object—called a *prototype*—to return a copy of that prototype to a requesting object—called a *client*. Every prototype must belong to a class that implements a common interface that allows the prototype to clone itself. For example, the Java API provides method **clone** from class **java.lang.Object** and interface **java.lang.Cloneable**—any object from a class implementing **Cloneable** can use method **clone** to copy itself. Specifically, method **clone** creates a copy of an object, then returns a reference to that object. If we designate class **MyLine** as the prototype for Exercise 9.28, then class **MyLine** must implement interface **Cloneable**. To create a new line in our drawing, we clone the **MyLine** prototype. To copy a preexisting line, we clone that object. Method **clone** also is useful in methods that return a reference to an object, but the developer does not want that object to be altered through that reference—method **clone** returns a reference to the copy of the object instead of returning that object's reference. For more information of interface **Cloneable**, visit

www.java.sun.com/j2se/1.3/docs/api/java/lang/Cloneable.html

21.12.2 Behavioral Design Patterns

We conclude the discussion of behavioral design patterns by discussing the Iterator design pattern.

Iterator

Designers use data structures such as arrays, linked lists and hash tables, to organize data in a program. The *Iterator design pattern* allows objects to access individual objects from any data structure without knowing the data structure's behavior (such as traversing the structure or removing an element from that structure) or how that data structure stores objects. Instructions for traversing the data structure and accessing its elements are stored in a separate object called an *iterator*. Each data structure can create an iterator—each iterator implements methods of a common interface to traverse the data structure and access its data. An object can traverse two differently structured data structures—such as a linked list and a hash table—in the same manner, because both data structures contain an iterator object that belongs to a class implementing a common interface. Java provides interface **Iterator** from package **java.util**, which we discussed in Section 21.5—class **CollectionTest** (Fig 21.3) uses an **Iterator** object.

21.12.3 Conclusion

In our optional "Discovering Design Patterns" sections, we have introduced the importance, usefulness and prevalence of design patterns. We have mentioned that in their book *Design Patterns, Elements of Reusable Object-Oriented Software*, the "gang of four" described 23 design patterns that provide proven strategies for building systems. Each pattern belongs to one of three pattern categories: creational, which address issues related to object creation; structural, which provide ways to organize classes and objects in a system; and behavioral, which offer strategies to model how objects collaborate with one another in a system.

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Of the 23 design patterns, we discussed 18 of the more popular ones used by the Java community. In Sections 9.24, 13.18, 15.13, 17.11 and 21.12, we divided the discussion according to how certain Java packages—such as package **java.awt**, **javax.swing**, **java.io**, **java.net** and **java.util**—use these design patterns. We also discussed patterns not described by the "gang of four," such as concurrency patterns, which are useful in multithreaded systems, and architectural patterns, which help designers assign functionality to various subsystems in a system. We have motivated each pattern—that is, explained why that pattern is important and how it may be used. When appropriate, we supplied several examples in the form of real-world analogies (e.g., the adapter in the Adapter design pattern is similar to an adapter for a plug on an electrical device). We also gave examples of how Java packages take advantage of design patterns (e.g., Swing GUI components use the Observer design pattern to collaborate with their listeners to respond to user interactions). We also provided examples of how certain programs in *Java How to Program, Fourth edition* used design patterns (e.g., the elevator-simulation case study in our optional "Thinking About Objects" sections uses the State design pattern to represent a **Person** object's location in the simulation).

We hope that you view our "Discovering Design Patterns" sections as a beginning to further study of design patterns. If you have not done so already, we recommend that you visit the many URLs we have provided in Section 9.24.5, Internet and World-Wide-Web Resources. We recommend that you then read the gang-of-four book. This information will help you build better systems using the collective wisdom of the object-technology industry.

If you have studied the optional sections in this book, you have been introduced to more substantial Java systems. If you have read our optional "Thinking About Objects" Sections, you have immersed yourself in a substantial design and Java implementation experience learning a disciplined approach to object-oriented design with the UML. If you have read our optional "Discovering Design Patterns" Sections, you have raised your awareness of the more advanced topic of design patterns.

We hope you continue your study of design patterns, and we would be most grateful if you would send your comments, criticisms and suggestions for improvement of *Java How to Program* to **deitel@deitel.com**. Good luck!

SUMMARY

- The Java collections framework gives the programmer access to prepackaged data structures, as well as algorithms for manipulating those data structures.
- Java 2 provides an entire collections framework, whereas earlier versions of Java provided just a few collection classes, like **HashTable** and **Vector**, as well as built-in array capabilities.
- A collection is a data structure; actually, it is an object that can hold other objects. The collection interfaces define the operations that can be performed on each type of collection.
- The collections framework includes a number of other features that minimize the amount of work programmers need to do to create and manipulate collections. This structure is an effective implementation of the notion of reuse.
- The classes and interfaces that compose the collections framework are members of the **java.util** package.
- Class **Arrays** provides **static** methods for manipulating arrays. Class **Arrays** methods include **binarySearch** for searching a sorted array, **equals** for comparing arrays, **fill** for placing items in an array, **sort** for sorting an array and **asList**.

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- Class **Arrays** provides method **asList** for getting a "**List** view" of the array. A **List** view allows the programmer to programmatically manipulate the array as if it were a **List**. This allows the programmer to treat an array as a collection. Any modifications made through the **List** view change the array, and any modifications to the array change the **List** view.
- Method **size** gets the number of items in a **List**, and method **get** gets an individual **List** element.
- Interface **Collection** is the root interface in the collections hierarchy from which interfaces **Set** and **List** are derived. Interface **Collection** contains bulk operations for adding, clearing, comparing and retaining objects in the collection.
- Interface **Collection** provides a method **iterator** for getting an **Iterator**.
- Class **Collections** provides **static** methods for manipulating collections. Many of the methods are implementations of polymorphic algorithms for searching, sorting and so on.
- A **List** is an ordered **Collection** that can contain duplicate elements. A **List** is sometimes called a *sequence*.
- Interface **List** is implemented by classes **ArrayList**, **LinkedList** and **Vector**. Class **ArrayList** is a resizable-array implementation of a **List**. **ArrayList** behavior and capabilities are similar to those of class **Vector**. A **LinkedList** is a linked-list implementation of a **List**.
- **Iterator** method **hasNext** determines whether a **Collection** contains another element. Method **hasNext** returns **true** if another element exists, **false** otherwise. Method **next** returns the next object in the **Collection** and advances the **Iterator**.
- Method **subList** gets a portion of a **List**, called a *sublist*. Any changes made to a sublist are also made to the **List** (i.e., the sublist is a "list view" of its corresponding **List** elements).
- Method **clear** removes elements from a **List**.
- Method **toArray** returns the contents of a collection as an array.
- Algorithms **sort**, **binarySearch**, **reverse**, **shuffle**, **fill** and **copy** operate on **List**s. Algorithms **min** and **max** operate on **Collections**. Algorithm **reverse** reverses the elements of a **List**, **fill** sets every **List** element to a specified **Object** and **copy** copies elements from one **List** into another **List**. Algorithm **sort** sorts the elements of a **List**.
- Algorithms **min** and **max** find the smallest item and the largest item in a **Collection**.
- The **Comparator** object provides a means of sorting a **Collection**'s elements in an order other than the **Collection**'s natural order.
- Method **reverseOrder** returns a **Comparator** object that represents the reverse order for a collection.
- Algorithm **shuffle** randomly orders the elements of a **List**.
- Algorithm **binarySearch** locates an **Object** in a **List**.
- A **Set** is a **Collection** that contains no duplicate elements. The collections framework contains two **Set** implementations: **HashSet** and **TreeSet**. **HashSet** stores its elements in a hash table; **TreeSet** stores its elements in a tree.
- Interface **SortedSet** extends **Set** and maintains its elements in sorted order. Class **TreeSet** implements **SortedSet**.
- Method **headSet** gets a subset of a **TreeSet** less than a specified element. Any changes made to the subset are made to the **TreeSet**. Method **tailSet** gets a subset greater than or equal to a specified element. Any changes made through the **tailSet** view are made to the **TreeSet**.
- **Map**s map keys to values and cannot contain duplicate keys. **Map**s differ from **Set**s in that **Map**s contain both keys and the values, whereas **Set**s contain only keys. Classes **HashMap** and

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TreeMap implement the **Map** interface. **HashMap**s store elements in a **HashTable**, and **TreeMap**s store elements in a tree.

- Interface **SortedMap** extends **Map** and maintains its elements in sorted order. Class **TreeMap** implements **SortedMap**.
- The built-in collections are unsynchronized. Concurrent access to a **Collection** by independent threads could cause indeterminate results. To prevent this, synchronization wrappers are used around classes that might be accessed by multiple threads.
- The **Collections** API provides a set of **public static** methods for converting collections to unmodifiable versions. Unmodifiable wrappers throw **UnsupportedOperationException**s if attempts are made to modify the collection.
- The collections framework provides various abstract implementations (i.e., "bare bones" implementations of collection interfaces from which the programmer can quickly "flesh out" complete customized implementations).

TERMINOLOGY

AbstractCollection class
AbstractList class
AbstractMap class
AbstractSequentialList class
AbstractSet class
add method
addFirst method
addLast method
algorithms
ArrayList
arrays
arrays as collections
Arrays.asList
bidirectional iterator
binarySearch algorithm
clear method
Collection interface
collections
Collections class
collections framework
collections placed in arrays
Comparator object
copy algorithm
data structures
delete an element from a collection
deque
double-ended queue (deque)
duplicate elements
Enumeration interface
fill algorithm
HashMap class
HashSet class
Hashtable class
hashtable implementation
hasNext method
implementation classes
insert an element into a collection
interface
isEmpty method
iterator
Iterator interface
key
lexicographical comparison
LinkedList class
List interface
ListIterator
map
Map collection interface
mapping keys to values
mappings
maps as collections
max algorithm
min algorithm
modifiable collections
natural ordering
next method
one-to-one mapping
ordered collection
ordering
queue
range-view methods
reverse algorithm
reverseOrder method
sequence
Set interface
shuffle algorithm
size method
sort a **List**

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sort algorithm
SortedMap collection interface
SortedSet collection interface
stable sort
synchronization wrappers
TreeMap class
TreeSet class
unmodifiable collections
Vector class
view
view an array as a **List**
wrapper class

SELF-REVIEW EXERCISES

21.1 Fill in the blanks in each of the following statements:
a) **Object**s in a collection are called _____.
b) An element in a **List** can be accessed by using the element's _____.
c) **List**s are sometimes called _____.
d) You can use a/an _____ to create a collection that offers only read-only access to others while allowing read–write access to yourself.
e) _____ can be used to create stacks, queues, trees and deques (double-ended queues).

21.2 State whether each of the following is *true* or *false*. If *false*, explain why.
a) A **Set** can contain duplicates.
b) A **Map** can contain duplicate keys.
c) A **LinkedList** can contain duplicates.
d) **Collections** is an **interface**.
e) **Iterator**s can remove elements, while **Enumeration**s cannot.

ANSWERS TO SELF-REVIEW EXERCISES

21.1 a) elements. b) index. c) sequences. d) unmodifiable wrapper. e) ***LinkedList***s.

21.2 a) False. A **Set** cannot contain duplicate values.
b) False. A **Map** cannot contain duplicate keys.
c) True.
d) False. **Collections** is a **class**, and **Collection** is an **interface**.
e) True.

EXERCISES

21.3 Define each of the following terms:
a) **Collection**
b) **Collections**
c) **Comparator**
d) **List**

21.4 Briefly answer the following questions:
a) What is the primary difference between a **Set** and a **Map**?
b) Can a double-subscripted array be passed to **Arrays** method **asList**? If yes, how would an individual element be accessed?
c) What must you do before adding a primitive data type (e.g., **double**) to a collection?

21.5 Explain briefly the operation of each of the following **Iterator**-related methods:
a) **iterator**
b) **hasNext**
c) **next**

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21.6 State whether each of the following is *true* or *false*. If *false*, explain why.
a) Elements in a **`Collection`** must be sorted in ascending order before performing a **`binarySearch`**.
b) Method **`first`** gets the first element in a **`TreeSet`**.
c) A **`List`** created with **`Arrays.asList`** is resizable.
d) Class **`Arrays`** provides static method **`sort`** for sorting array elements.

21.7 Rewrite method **`printList`** of Fig. 21.4 to use a **`ListIterator`**.

21.8 Rewrite lines 16–23 in Fig. 21.4 to be more concise by using the **`asList`** method and the **`LinkedList`** constructor that takes a **`Collection`** argument.

21.9 Write a program that reads in a series of first names and stores them in a **`LinkedList`**. Do not store duplicate names. Allow the user to search for a first name.

21.10 Modify the program of Fig. 21.13 to count the number of occurrences of all letters (e.g., five occurrences of "o" in the example). Display the results.

21.11 Write a program that determines and prints the number of duplicate words in a sentence. Treat uppercase and lowercase letters the same. Ignore punctuation.

21.12 Rewrite your solution to Exercise 19.8 to use a **`LinkedList`** collection.

21.13 Rewrite your solution to Exercise 19.9 to use a **`LinkedList`** collection.

21.14 Write a program that takes a whole-number input from a user and determines if it is prime. If the number is prime, add it to a **`JTextArea`**. If the number is not prime, display the prime factors of the number in a **`JLabel`**. Remember that a prime number's factors are only 1 and the prime number itself. Every number that is not prime has a unique prime factorization. For example, consider the number 54. The factors of 54 are 2, 3, 3 and 3. When the values are multiplied together, the result is 54. For the number 54, the prime factors output should be 2 and 3. Use **`Set`**s as part of your solution.

21.15 Rewrite your solution to Exercise 22.21 to use a **`LinkedList`**.

21.16 Write a program that tokenizes (using class **`StreamTokenizer`**) a line of text input by the user and places each token in a tree. Print the elements of the sorted tree.

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22

Java Media Framework and Java Sound (on CD)

Objectives

- To understand the capabilities of the Java Media Framework (JMF).
- To understand the capabilities of the Java Sound API.
- To be able to play audio and video media with JMF.
- To be able to stream media over a network.
- To be able to capture, format and save media.
- To be able to play sounds with the Java Sound API.
- To be able to play, record, and synthesize MIDI with the Java Sound API.

TV gives everyone an image, but radio gives birth to a million images in a million brains.
Peggy Noonan

Noise proves nothing. Often a hen who has merely laid an egg cackles as if she had laid an asteroid.
Mark Twain, *Following the Equator*

A wide screen just makes a bad film twice as bad.
Samuel Goldwyn

Isn't life a series of images that change as they repeat themselves?
Andy Warhol

Outline

22.1 Introduction
22.2 Playing Media
22.3 Formatting and Saving Captured Media
22.4 RTP Streaming
22.5 Java Sound
22.6 Playing Sampled Audio
22.7 Musical Instrument Digital Interface (MIDI)
22.7.1 MIDI Playback
22.7.2 MIDI Recording
22.7.3 MIDI Synthesis
22.8 Internet and World Wide Web Resources
22.9 (Optional Case Study) Thinking About Objects: Animation and Sound in the View

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

22.1 Introduction

This chapter continues our multimedia discussions of Chapter 18 by introducing some of Java's multimedia APIs that enable programmers to enhance applications with video and audio features. In recent years, the digital multimedia sector of the computer industry has experienced tremendous growth, as evidenced by the enormous quantity of multimedia content available on the Internet. Web sites have been transformed from text-based HTML pages to multimedia-intensive experiences. Advances in hardware and software technologies have allowed developers to integrate multimedia into the simplest applications. At the high end of multimedia applications, the video game industry has used multimedia programming to take advantage of the latest hardware technologies, such as 3D video cards that create virtual reality experiences for users.

Acknowledging that Java applications should support digital video and audio capabilities, Sun Microsystems, Intel and Silicon Graphics worked together to produce a multimedia API known as the *Java Media Framework (JMF)*. The JMF API is one of several multimedia APIs in Java. Using the JMF API, programmers can create Java applications that play, edit, stream and capture many popular media types. The first half of this chapter discusses the JMF API.

IBM and Sun developed the latest JMF specification—version 2.0. Sun provides a reference implementation—JMF 2.1.1—of the JMF specification which supports media file types such as *Microsoft Audio/Video Interleave* (`.avi`), *Macromedia Flash 2 movies* (`.swf`), *Future Splash* (`.spl`), *MPEG Layer 3 Audio* (`.mp3`), *Musical Instrument Digital Interface* (*MIDI*; `.mid`), *MPEG-1 videos* (`.mpeg`, `.mpg`), *QuickTime* (`.mov`), *Sun Audio* (`.au`), *Wave audio* (`.wav`), *AIFF* (`.aiff`) and *GSM* (`.gsm`) files. The JMF also supports media from capture devices such as microphones and digital cameras.

In addition to the sample media clips provided with this chapter's examples on the CD, many Web sites offer an abundant supply of free-for-download audio and video clips. You can download media clips from these sites (and many others on the Internet) and use them to test the examples in this chapter. We present a list of sites here to get you started. *Free Audio Clips* (**www.freeaudioclips.com**) is an excellent site for various types of audio files. The *13 Even* site (**www.13-even.com/media.html**) provides audio and video clips in many formats for your personal use. If you are looking for MIDI audio files for use in Section 22.7, check out the free MIDI clips at **www.freestuffgalore.commidi.asp**. *Funny Video Clips* (**www.video-clips.co.uk**) offers entertaining material. Microsoft's downloads site (**msdn.microsoft.com/downloads**) contains a multimedia section providing audio clips and other media.

Currently, JMF is available as an extension package separate from the Java 2 Software Development Kit. The CD that accompanies this book contains JMF 2.1.1. The most recent JMF implementation can be downloaded from the official JMF Web site:

```
java.sun.com/products/java-media/jmf
```

The JMF Web site provides versions of the JMF that take advantage of the performance features of the platform on which the JMF is running. For example, the JMF *Windows Performance Pack* provides extensive media and device support for Java programs running on Microsoft Windows platforms (Windows 95/98/NT 4.0/2000). JMF's official Web site also provides continually updated support, information and resources for JMF programmers.

Portability Tip 22.1

Writing programs using JMF's Windows Performance Pack reduces the portability of those programs to other operating systems.

The rest of this chapter discusses the *Java Sound API* and its extensive sound-processing capabilities. Internally, the JMF uses Java Sound for its audio functions. In Sections 22.5 through 22.7, we will demonstrate sampled audio playback and MIDI functionalities using Java Sound, a standard extension of the Java 2 Software Development Kit.

22.2 Playing Media

The JMF is commonly used to playback media clips in Java applications. Many applications such as financial managers, encyclopedias and games use multimedia to illustrate application features, present educational content and entertain users.

The JMF offers several mechanisms for playing media, the simplest of which is via objects that implement interface ***Player***. Interface **Player** (package **javax.media**) extends ***Controller***, which is a handler for JMF-supported media.

The following steps are needed to play a media clip:

1. Specify the media source.
2. Create a **Player** for the media.
3. Obtain the output media and **Player** controls.
4. Display the media and controls.

Class **SimplePlayer** (Fig. 22.1) is a simple Java media player program that demonstrates several common features of popular media players. The **SimplePlayer** demo

can play most JMF-supported media files with the possible exception of the latest versions of the formats. This application permits users to access files on the local computer that contain supported media types by clicking the **Open File** button. Clicking the **Open Location** button and specifying a media URL allows the user to access media from a media source, such as a *capture device*, a Web server, or a *streaming source*. A capture device (discussed in Section 22.3) reads media from audio and video devices such as microphones, CD players and cameras. A *Real-Time Transport Protocol* (*RTP*) *stream* is a stream of bytes sent over a network from a streaming server. An application buffers and plays the streaming media on the client computer.

```
1  // Fig. 22.1: SimplePlayer.java
2  // Opens and plays a media file from
3  // local computer, public URL, or an RTP session
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.io.*;
9  import java.net.*;
10
11 // Java extension packages
12 import javax.swing.*;
13 import javax.media.*;
14
15 public class SimplePlayer extends JFrame {
16
17    // Java media player
18    private Player player;
19
20    // visual content component
21    private Component visualMedia;
22
23    // controls component for media
24    private Component mediaControl;
25
26    // main container
27    private Container container;
28
29    // media file and media locations
30    private File mediaFile;
31    private URL fileURL;
32
33    // constructor for SimplePlayer
34    public SimplePlayer()
35    {
36       super( "Simple Java Media Player" );
37
38       container = getContentPane();
39
40       // panel containing buttons
41       JPanel buttonPanel = new JPanel();
```

Fig. 22.1 Playing media with interface **`Player`** (part 1 of 8).

```
42          container.add( buttonPanel, BorderLayout.NORTH );
43
44          // opening file from directory button
45          JButton openFile = new JButton( "Open File" );
46          buttonPanel.add( openFile );
47
48          // register an ActionListener for openFile events
49          openFile.addActionListener(
50
51             // anonymous inner class to handle openFile events
52             new ActionListener() {
53
54                // open and create player for file
55                public void actionPerformed( ActionEvent event )
56                {
57                   mediaFile = getFile();
58
59                   if ( mediaFile != null ) {
60
61                      // obtain URL from file
62                      try {
63                         fileURL = mediaFile.toURL();
64                      }
65
66                      // file path unresolvable
67                      catch ( MalformedURLException badURL ) {
68                         badURL.printStackTrace();
69                         showErrorMessage( "Bad URL" );
70                      }
71
72                      makePlayer( fileURL.toString() );
73
74                   }
75
76                }  // end actionPerformed
77
78             }  // end ActionListener
79
80          ); // end call to method addActionListener
81
82          // URL opening button
83          JButton openURL = new JButton( "Open Locator" );
84          buttonPanel.add( openURL );
85
86          // register an ActionListener for openURL events
87          openURL.addActionListener(
88
89             // anonymous inner class to handle openURL events
90             new ActionListener() {
91
92                // open and create player for media locator
93                public void actionPerformed( ActionEvent event )
94                {
```

Fig. 22.1 Playing media with interface **`Player`** (part 2 of 8).

```
95                String addressName = getMediaLocation();
96
97                if ( addressName != null )
98                   makePlayer( addressName );
99             }
100
101         }  // end ActionListener
102
103      ); // end call to method addActionListener
104
105      // turn on lightweight rendering on players to enable
106      // better compatibility with lightweight GUI components
107      Manager.setHint( Manager.LIGHTWEIGHT_RENDERER,
108         Boolean.TRUE );
109
110   }  // end SimplePlayer constructor
111
112   // utility method for pop-up error messages
113   public void showErrorMessage( String error )
114   {
115      JOptionPane.showMessageDialog( this, error, "Error",
116         JOptionPane.ERROR_MESSAGE );
117   }
118
119   // get file from computer
120   public File getFile()
121   {
122      JFileChooser fileChooser = new JFileChooser();
123
124      fileChooser.setFileSelectionMode(
125         JFileChooser.FILES_ONLY );
126
127      int result = fileChooser.showOpenDialog( this );
128
129      if ( result == JFileChooser.CANCEL_OPTION )
130         return null;
131
132      else
133         return fileChooser.getSelectedFile();
134   }
135
136   // get media location from user input
137   public String getMediaLocation()
138   {
139      String input = JOptionPane.showInputDialog(
140         this, "Enter URL" );
141
142      // if user presses OK with no input
143      if ( input != null && input.length() == 0 )
144         return null;
145
146      return input;
147   }
```

Fig. 22.1 Playing media with interface **`Player`** (part 3 of 8).

```
148
149    // create player using media's location
150    public void makePlayer( String mediaLocation )
151    {
152       // reset player and window if previous player exists
153       if ( player != null )
154          removePlayerComponents();
155
156       // location of media source
157       MediaLocator mediaLocator =
158          new MediaLocator( mediaLocation );
159
160       if ( mediaLocator == null ) {
161          showErrorMessage( "Error opening file" );
162          return;
163       }
164
165       // create a player from MediaLocator
166       try {
167          player = Manager.createPlayer( mediaLocator );
168
169          // register ControllerListener to handle Player events
170          player.addControllerListener(
171             new PlayerEventHandler() );
172
173          // call realize to enable rendering of player's media
174          player.realize();
175       }
176
177       // no player exists or format is unsupported
178       catch ( NoPlayerException noPlayerException ) {
179          noPlayerException.printStackTrace();
180       }
181
182       // file input error
183       catch ( IOException ioException ) {
184          ioException.printStackTrace();
185       }
186
187    }  // end makePlayer method
188
189    // return player to system resources and
190    // reset media and controls
191    public void removePlayerComponents()
192    {
193      // remove previous video component if there is one
194      if ( visualMedia != null )
195         container.remove( visualMedia );
196
197      // remove previous media control if there is one
198      if ( mediaControl != null )
199         container.remove( mediaControl );
200
```

Fig. 22.1 Playing media with interface **`Player`** (part 4 of 8).

```
201       // stop player and return allocated resources
202       player.close();
203    }
204
205    // obtain visual media and player controls
206    public void getMediaComponents()
207    {
208       // get visual component from player
209       visualMedia = player.getVisualComponent();
210
211       // add visual component if present
212       if ( visualMedia != null )
213          container.add( visualMedia, BorderLayout.CENTER );
214
215       // get player control GUI
216       mediaControl = player.getControlPanelComponent();
217
218       // add controls component if present
219       if ( mediaControl != null )
220          container.add( mediaControl, BorderLayout.SOUTH );
221
222    }  // end method getMediaComponents
223
224    // handler for player's ControllerEvents
225    private class PlayerEventHandler extends ControllerAdapter {
226
227       // prefetch media feed once player is realized
228       public void realizeComplete(
229          RealizeCompleteEvent realizeDoneEvent )
230       {
231          player.prefetch();
232       }
233
234       // player can start showing media after prefetching
235       public void prefetchComplete(
236          PrefetchCompleteEvent prefetchDoneEvent )
237       {
238          getMediaComponents();
239
240          // ensure valid layout of frame
241          validate();
242
243          // start playing media
244          player.start();
245
246       }  // end prefetchComplete method
247
248       // if end of media, reset to beginning, stop play
249       public void endOfMedia( EndOfMediaEvent mediaEndEvent )
250       {
251          player.setMediaTime( new Time( 0 ) );
252          player.stop();
253       }
```

Fig. 22.1 Playing media with interface **`Player`** (part 5 of 8).

```
254
255     }  // end PlayerEventHandler inner class
256
257     // execute application
258     public static void main( String args[] )
259     {
260        SimplePlayer testPlayer = new SimplePlayer();
261
262        testPlayer.setSize( 300, 300 );
263        testPlayer.setLocation( 300, 300 );
264        testPlayer.setDefaultCloseOperation( EXIT_ON_CLOSE );
265        testPlayer.setVisible( true );
266     }
267
268  }  // end class SimplePlayer
```

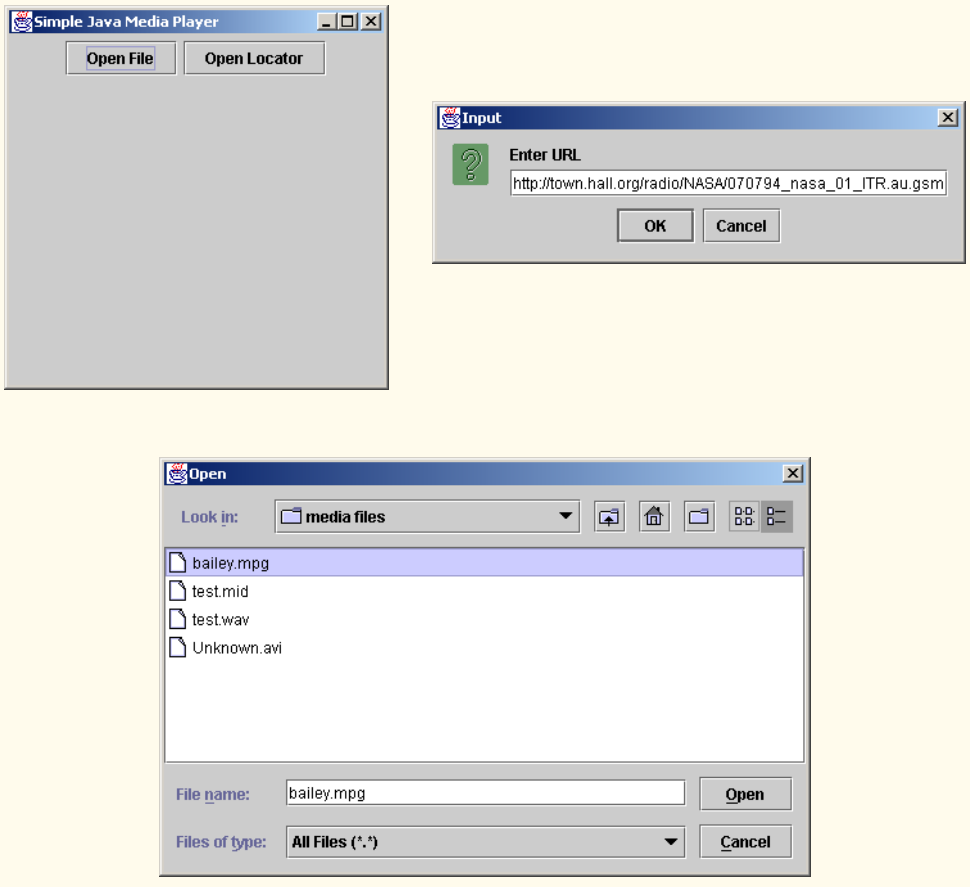

Fig. 22.1 Playing media with interface **`Player`** (part 6 of 8).

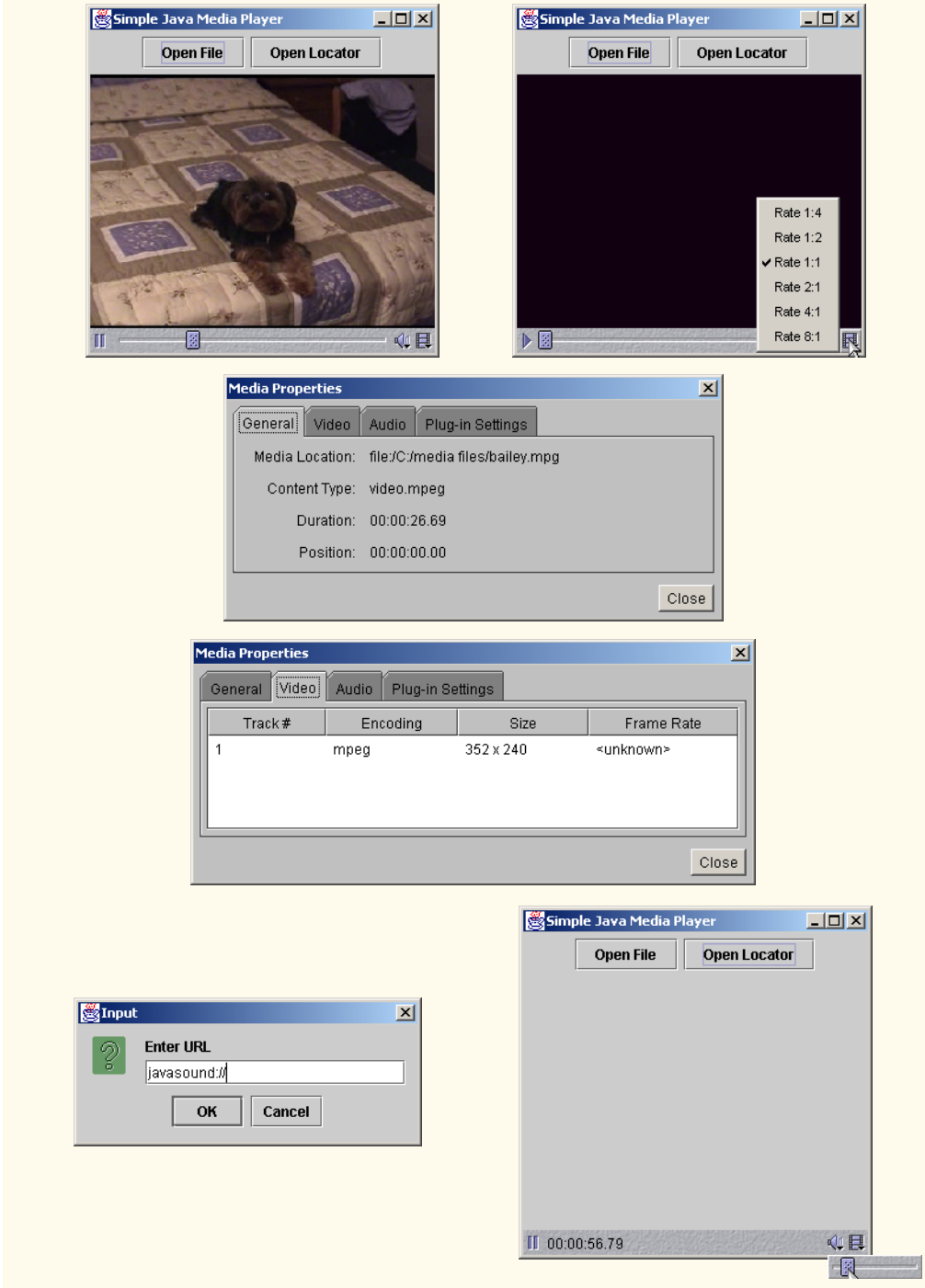

Fig. 22.1 Playing media with interface **`Player`** (part 7 of 8).

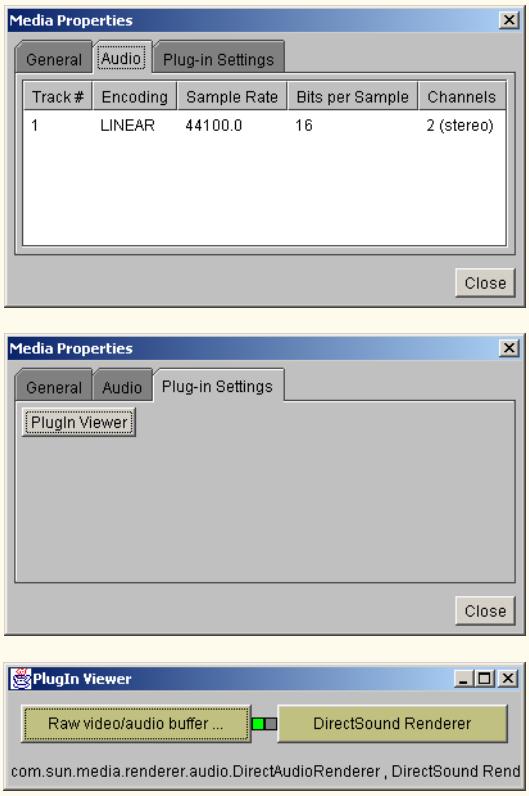

Fig. 22.1 Playing media with interface **`Player`** (part 8 of 8).

A media clip must be processed before it is played. To process a media clip the program must access a media source, create a **`Controller`** for that source and output the media. Prior to output, users may perform optional formatting such as changing an AVI video to a QuickTime video. Although JMF hides low-level media processing (e.g. checking for file compatibility) from the programmer, both programmers and users can configure how a **`Player`** presents media. Section 22.3 and Section 22.4 reveal that capturing and streaming media follow the same guidelines. Section 22.8 lists several Web sites that have JMF-supported media contents.

Figure 22.1 introduces some key objects for playing media. The JMF extension package **`javax.media`**—imported in line 13—contains interface **`Player`** and other classes and interfaces needed for events. Line 18 declares a **`Player`** object to play media clips. Lines 30–31 declare the location of these clips as **`File`** and **`URL`** references.

Lines 21 and 24 declare **`Component`** objects for the video display and for holding the controls. **`Component mediaControl`** enables users to play, pause and stop the media clip. **`Component visualMedia`** displays the video portion of a media clip (if the media clip is a video). The JMF provides lightweight video renderers that are compatible with lightweight Swing components (See Chapter 13). Lines 107–108 in **`SimplePlayer`**'s constructor specify that the **`Player`** should draw its GUI components and video portion (if there

is one) using lightweight renderers so that the media player will look like other GUIs with Swing components. By default, **Player**'s video components are heavyweight components, which may not display correctly when mixed with lightweight Swing GUI components.

Before playing the media, **SimplePlayer** displays an initial GUI consisting of two buttons, **Open File** and **Open Locator**, that enable users to specify the media location. The event handlers for these two buttons (lines 52–78 and lines 90–101) perform similar functions. Each button prompts users for a media resource such as an audio or video clip, then creates a **Player** for the specified media. When the user clicks **Open File**, line 57 calls method **getFile** (lines 120–134) to prompt users to select a media file from the local computer. Line 63 calls the **File** method **toURL** to obtain a **URL** representation of the selected file's name and location. Line 72 calls **SimplePlayer** method **makePlayer** (lines 150–187) to create a **Player** for the user-selected media. When users click **Open Locator**, line 95 invokes method **getMediaLocation** (lines 137–147), prompting users to input a **String** giving the media location. Line 98 calls **SimplePlayer** method **makePlayer** to create a **Player** for the media at the specified location.

Method **makePlayer** (lines 150–187) makes the necessary preparations to create a **Player** of media clips. The **String** argument indicates the media's location. Lines 153–154 invoke **SimplePlayer** method **removePlayerComponents** (lines 191–203) to remove the previous **Player**'s visual component and GUI controls from the frame before creating a new **Player**. Line 202 invokes **Player** method **close** to stop all **player** activity and to release system resources held by the previous **Player**.

Method **makePlayer** requires a pointer to the source from which the media is retrieved, which is accomplished by instantiating a new ***MediaLocator*** for the value given by the **String** argument (lines 157–158). A **MediaLocator** specifies the location of a media source, much like a **URL** typically specifies the location of a Web page. A **MediaLocator** can access media from capture devices and RTP sessions as well as from file locations. The **MediaLocator** constructor requires the media's location as a **String**, so all **URL**s must be converted to **String**s as in line 72.

Method **makePlayer** instantiates a new **Player** with a call to ***Manager*** method ***createPlayer***. Class **Manager** provides **static** methods that enable programs to access most JMF resources. Method **createPlayer** opens the specified media source and determines the appropriate **Player** for the media source. Method **createPlayer** throws a ***NoPlayerException*** if an appropriate **Player** cannot be found for the media clip. An **IOException** is thrown if there are problems connecting to the media source.

ControllerListeners listen for the ***ControllerEvent***s that **Player**s generate to track the progress of a **Player** in the media-handling process. Lines 170–171 register an instance of inner class **PlayerEventHandler** (lines 225–255) to listen for certain events that **player** generates. Class **PlayerEventHandler** extends class ***ControllerAdapter***, which provides empty implementations of methods from interface **ControllerListener**. Class **ControllerAdapter** facilitates implementing **ControllerListener** for classes that need to handle only a few **ControllerEvent** types.

Players confirm their progress while the processing media based on their state transitions. Line 174 invokes **Player** method ***realize*** to confirm all resources necessary to play media are available. Method **realize** places the **Player** in the *Realizing* state to indicate that it is connecting to and interacting with its media sources. When a **Player**

completes realizing, it generates a **`RealizeCompleteEvent`**—a type of **`ControllerEvent`** that occurs when a **`Player`** completes its transition to state *Realized*. This state indicates that the **`Player`** has completed all preparations needed to start processing the media. The program invokes method **`realizeComplete`** (lines 228–232) when **`Player`** generates a **`RealizeCompleteEvent`**.

Most media players have a buffering feature, which stores a portion of downloaded media locally so that users do not have to wait for an entire clip to download before playing it, as reading media data can take a long time. By invoking **`Player`** method **`prefetch`**, line 231 transitions the **`player`** to the *Prefetching* state. When a **`Player`** prefetches a media clip, the **`Player`** obtains exclusive control over certain system resources needed to play the clip. The **`Player`** also begins buffering media data to reduce the delay before the media clip plays.

When the **`Player`** completes prefetching, it transitions to state *Prefetched* and is ready to play media. During this transition, the **`Player`** generates a **`ControllerEvent`** of type **`PrefetchCompleteEvent`** to indicate that it is ready to display media. The **`Player`** invokes **`PlayerEventHandler`** method **`prefetchComplete`** (lines 235–246), which displays the **`Player`**'s GUI in the frame. After obtaining the hardware resources, the program can get the media components it requires. Line 238 invokes method **`getMediaComponents`** (lines 206–222) to obtain the GUI's controls and the media's visual component (if the media is a video clip) and attach them to the application window's content pane. **`Player`** method **`getVisualComponent`** (line 209) obtains the visual component of the video clip. Similarly, line 216 invokes **`Player`** method **`getControlPanelComponent`** to return the GUI's controls. The GUI (Fig. 22.1) typically provides the following controls:

1. A positioning slider to jump to certain points in the media clip.
2. A pause button.
3. A volume button that provides volume control by right clicking and a mute function by left clicking.
4. A media properties button that provides detailed media information by right clicking and frame rate control by left clicking.

Look-and-Feel Observation 22.1

*Invoking **`Player`** method **`getVisualComponent`** yields **`null`** for audio files, because there is no visual component to display.*

Look-and-Feel Observation 22.2

*Invoking **`Player`** method **`getControlPanelComponent`** yields different sets of GUI controls depending on the media type. For example, media content streamed directly from a live conference does not have a progress bar because the length of the media is not pre-determined.*

After validating the new frame layout (line 241), line 244 invokes **`Player`** method **`start`** (line 239) to start playing the media clip.

Software Engineering Observation 22.1

*If the **`Player`** has not prefetched or realized the media, invoking **`Player`** method **`start`** prefetches and realizes the media.*

Performance Tip 22.1

Starting the **`Player`** *takes less time if the* **`Player`** *has already prefetched the media before invoking start.*

When the media clip ends, the **`Player`** generates a **`ControllerEvent`** of type ***`EndOfMediaEvent`***. Most media players "rewind" the media clip after reaching the end so users can see or hear it again from the beginning. Method **`endOfMedia`** (lines 249–253) handles the **`EndOfMediaEvent`** and resets the media clip to its beginning position by invoking **`Player`** method ***`setMediaTime`*** with a new ***`Time`*** (package **`javax.media`**) of **`0`** (line 251). Method **`setMediaTime`** sets the position of the media to a specific time location in the media, and is useful for "jumping" to a different part of the media. Line 252 invokes **`Player`** method ***`stop`***, which ends media processing and places the **`Player`** in state *Stopped*. Invoking method **`start`** on a *Stopped* **`Player`** that has not been closed resumes media playback.

Often, it is desirable to configure the media before presentation. In the next section, we discuss interface ***`Processor`***, which has more configuration capabilities than interface **`Player`**. **`Processor`**s enable a program to format media and to save it to a file.

22.3 Formatting and Saving Captured Media

The Java Media Framework supports playing and saving media from capture devices such as microphones and video cameras. This type of media is known as *captured media*. Capture devices convert analog media into digitized media. For example, a program that captures an analog voice from a microphone attached to computer can create a digitized file from a that recording.

The JMF can access video capture devices that use *Video for Windows* drivers. Also, JMF supports audio capture devices that use the Windows *Direct Sound Interface* or the *Java Sound Interface*. The Video for Windows driver provides interfaces that enable Windows applications to access and process media from video devices. Similarly, Direct Sound and Java Sound are interfaces that enable applications to access sound devices such as hardware sound cards. The Solaris Performance Pack provides support for Java Sound and Sun Video capture devices on the Solaris platform. For a complete list of devices supported by JMF, visit JMF's official Web site.

The **`SimplePlayer`** application presented in Fig. 22.1 allowed users to play media from a capture device. A *locator string* specifies the location of a capture device that the **`SimplePlayer`** demo accesses. For example, to test the **`SimplePlayer`**'s capturing capabilities, plug a microphone into a sound card's microphone input jack. Typing the locator string **`javasound://`** in the **Open Location** input dialog specifies that media should be input from the Java Sound-enabled capture device. The locator string initializes the **`MediaLocator`** that the **`Player`** needs for the audio material captured from the microphone.

Although **`SimplePlayer`** provides access to capture devices, it does not format the media or save captured data. Figure 22.2 presents a program that accomplishes these two new tasks. Class **`CapturePlayer`** provides more control over media properties via class ***`DataSource`*** (package **`javax.media.protocol`**). Class **`DataSource`** provides the connection to the media source, then abstracts that connection to allow users to manipulate it. This program uses a **`DataSource`** to format the input and output media. The **`DataSource`** passes the formatted output media to a **`Controller`**, which will format it

further so that it can be saved to a file. The **`Controller`** that handles media is a **`Processor`**, which extends interface **`Player`**. Finally, an object that implements interface ***`DataSink`*** saves the captured, formatted media. The **`Processor`** object handles the flow of data from the **`DataSource`** to the **`DataSink`** object.

JMF and Java Sound use media sources extensively, so programmers must understand the arrangement of data in the media. The *header* on a media source specifies the media format and other essential information needed to play the media. The media content usually consists of *tracks* of data, similar to tracks of music on a CD. Media sources may have one or more tracks that contain a variety of data. For example, a movie clip may contain one track for video, one track for audio, and a third track for closed-captioning data for the hearing-impaired.

```
1  // Fig. 22.2: CapturePlayer.java
2  // Presents and saves captured media
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.io.*;
8  import java.util.*;
9
10 // Java extension packages
11 import javax.swing.*;
12 import javax.swing.event.*;
13 import javax.media.*;
14 import javax.media.protocol.*;
15 import javax.media.format.*;
16 import javax.media.control.*;
17 import javax.media.datasink.*;
18
19 public class CapturePlayer extends JFrame {
20
21    // capture and save button
22    private JButton captureButton;
23
24    // component for save capture GUI
25    private Component saveProgress;
26
27    // formats of device's media, user-chosen format
28    private Format formats[], selectedFormat;
29
30    // controls of device's media formats
31    private FormatControl formatControls[];
32
33    // specification information of device
34    private CaptureDeviceInfo deviceInfo;
35
36    // vector containing all devices' information
37    private Vector deviceList;
38
```

Fig. 22.2 Formatting and saving media from capture devices (part 1 of 9).

```
39      // input and output data sources
40      private DataSource inSource, outSource;
41
42      // file writer for captured media
43      private DataSink dataSink;
44
45      // processor to render and save captured media
46      private Processor processor;
47
48      // constructor for CapturePlayer
49      public CapturePlayer()
50      {
51         super( "Capture Player" );
52
53         // panel containing buttons
54         JPanel buttonPanel = new JPanel();
55         getContentPane().add( buttonPanel );
56
57         // button for accessing and initializing capture devices
58         captureButton = new JButton( "Capture and Save File" );
59         buttonPanel.add( captureButton, BorderLayout.CENTER );
60
61         // register an ActionListener for captureButton events
62         captureButton.addActionListener( new CaptureHandler() );
63
64         // turn on light rendering to enable compatibility
65         // with lightweight GUI components
66         Manager.setHint( Manager.LIGHTWEIGHT_RENDERER,
67            Boolean.TRUE );
68
69         // register a WindowListener to frame events
70         addWindowListener(
71
72            // anonymous inner class to handle WindowEvents
73            new WindowAdapter() {
74
75               // dispose processor
76               public void windowClosing(
77                  WindowEvent windowEvent )
78               {
79                  if ( processor != null )
80                     processor.close();
81               }
82
83            }  // end WindowAdapter
84
85         ); // end call to method addWindowListener
86
87      }  // end constructor
88
89      // action handler class for setting up device
90      private class CaptureHandler implements ActionListener {
91
```

Fig. 22.2 Formatting and saving media from capture devices (part 2 of 9).

```
92          // initialize and configure capture device
93          public void actionPerformed( ActionEvent actionEvent )
94          {
95             // put available devices' information into vector
96             deviceList =
97                CaptureDeviceManager.getDeviceList( null );
98
99             // if no devices found, display error message
100            if ( ( deviceList == null ) ||
101               ( deviceList.size() == 0 ) ) {
102
103               showErrorMessage( "No capture devices found!" );
104
105               return;
106            }
107
108            // array of device names
109            String deviceNames[] = new String[ deviceList.size() ];
110
111            // store all device names into array of
112            // string for display purposes
113            for ( int i = 0; i < deviceList.size(); i++ ){
114
115               deviceInfo =
116                  ( CaptureDeviceInfo ) deviceList.elementAt( i );
117
118               deviceNames[ i ] = deviceInfo.getName();
119            }
120
121            // get vector index of selected device
122            int selectDeviceIndex =
123               getSelectedDeviceIndex( deviceNames );
124
125            if ( selectDeviceIndex == -1 )
126               return;
127
128            // get device information of selected device
129            deviceInfo = ( CaptureDeviceInfo )
130               deviceList.elementAt( selectDeviceIndex );
131
132            formats = deviceInfo.getFormats();
133
134            // if previous capture device opened, disconnect it
135            if ( inSource != null )
136               inSource.disconnect();
137
138            // obtain device and set its format
139            try {
140
141               // create data source from MediaLocator of device
142               inSource = Manager.createDataSource(
143                  deviceInfo.getLocator() );
144
```

Fig. 22.2 Formatting and saving media from capture devices (part 3 of 9).

```
145             // get format setting controls for device
146             formatControls = ( ( CaptureDevice )
147                inSource ).getFormatControls();
148
149             // get user's desired device format setting
150             selectedFormat = getSelectedFormat( formats );
151
152             if ( selectedFormat == null )
153                return;
154
155             setDeviceFormat( selectedFormat );
156
157             captureSaveFile();
158
159          }  // end try
160
161          // unable to find DataSource from MediaLocator
162          catch ( NoDataSourceException noDataException ) {
163             noDataException.printStackTrace();
164          }
165
166          // device connection error
167          catch ( IOException ioException ) {
168             ioException.printStackTrace();
169          }
170
171       }  // end method actionPerformed
172
173    }  // end inner class CaptureHandler
174
175    // set output format of device-captured media
176    public void setDeviceFormat( Format currentFormat )
177    {
178       // set desired format through all format controls
179       for ( int i = 0; i < formatControls.length; i++ ) {
180
181          // make sure format control is configurable
182          if ( formatControls[ i ].isEnabled() ) {
183
184             formatControls[ i ].setFormat( currentFormat );
185
186             System.out.println (
187                "Presentation output format currently set as " +
188                formatControls[ i ].getFormat() );
189          }
190
191       }  // end for loop
192    }
193
194    // get selected device vector index
195    public int getSelectedDeviceIndex( String[] names )
196    {
```

Fig. 22.2 Formatting and saving media from capture devices (part 4 of 9).

```
197         // get device name from dialog box of device choices
198         String name = ( String ) JOptionPane.showInputDialog(
199            this, "Select a device:", "Device Selection",
200            JOptionPane.QUESTION_MESSAGE,
201            null, names, names[ 0 ] );
202
203         // if format selected, get index of name in array names
204         if ( name != null )
205            return Arrays.binarySearch( names, name );
206
207         // else return bad selection value
208         else
209            return -1;
210      }
211
212      // return user-selected format for device
213      public Format getSelectedFormat( Format[] showFormats )
214      {
215         return ( Format ) JOptionPane.showInputDialog( this,
216            "Select a format: ", "Format Selection",
217            JOptionPane.QUESTION_MESSAGE,
218            null, showFormats, null );
219      }
220
221      // pop up error messages
222      public void showErrorMessage( String error )
223      {
224         JOptionPane.showMessageDialog( this, error, "Error",
225            JOptionPane.ERROR_MESSAGE );
226      }
227
228      // get desired file for saved captured media
229      public File getSaveFile()
230      {
231         JFileChooser fileChooser = new JFileChooser();
232
233         fileChooser.setFileSelectionMode(
234            JFileChooser.FILES_ONLY );
235         int result = fileChooser.showSaveDialog( this );
236
237         if ( result == JFileChooser.CANCEL_OPTION )
238            return null;
239
240         else
241            return fileChooser.getSelectedFile();
242      }
243
244      // show saving monitor of captured media
245      public void showSaveMonitor()
246      {
```

Fig. 22.2 Formatting and saving media from capture devices (part 5 of 9).

```
247         // show saving monitor dialog
248         int result = JOptionPane.showConfirmDialog( this,
249            saveProgress, "Save capture in progress...",
250            JOptionPane.DEFAULT_OPTION,
251            JOptionPane.INFORMATION_MESSAGE );
252
253         // terminate saving if user presses "OK" or closes dialog
254         if ( ( result == JOptionPane.OK_OPTION ) ||
255            ( result == JOptionPane.CLOSED_OPTION ) ) {
256
257            processor.stop();
258            processor.close();
259
260            System.out.println ( "Capture closed." );
261         }
262      }
263
264      // process captured media and save to file
265      public void captureSaveFile()
266      {
267         // array of desired saving formats supported by tracks
268         Format outFormats[] = new Format[ 1 ];
269
270         outFormats[ 0 ] = selectedFormat;
271
272         // file output format
273         FileTypeDescriptor outFileType =
274            new FileTypeDescriptor( FileTypeDescriptor.QUICKTIME );
275
276         // set up and start processor and monitor capture
277         try {
278
279            // create processor from processor model
280            // of specific data source, track output formats,
281            // and file output format
282            processor = Manager.createRealizedProcessor(
283               new ProcessorModel( inSource, outFormats,
284                  outFileType ) );
285
286            // try to make a data writer for media output
287            if ( !makeDataWriter() )
288               return;
289
290            // call start on processor to start captured feed
291            processor.start();
292
293            // get monitor control for capturing and encoding
294            MonitorControl monitorControl =
295               ( MonitorControl ) processor.getControl(
296               "javax.media.control.MonitorControl" );
297
298            // get GUI component of monitoring control
299            saveProgress = monitorControl.getControlComponent();
```

Fig. 22.2 Formatting and saving media from capture devices (part 6 of 9).

```
300
301            showSaveMonitor();
302
303         }  // end try
304
305         // no processor could be found for specific
306         // data source
307         catch ( NoProcessorException processorException ) {
308            processorException.printStackTrace();
309         }
310
311         // unable to realize through
312         // createRealizedProcessor method
313         catch ( CannotRealizeException realizeException ) {
314            realizeException.printStackTrace();
315         }
316
317         // device connection error
318         catch ( IOException ioException ) {
319            ioException.printStackTrace();
320         }
321
322      }  // end method captureSaveFile
323
324      // method initializing media file writer
325      public boolean makeDataWriter()
326      {
327         File saveFile = getSaveFile();
328
329         if ( saveFile == null )
330            return false;
331
332         // get output data source from processor
333         outSource = processor.getDataOutput();
334
335         if ( outSource == null ) {
336            showErrorMessage( "No output from processor!" );
337            return false;
338         }
339
340         // start data writing process
341         try {
342
343            // create new MediaLocator from saveFile URL
344            MediaLocator saveLocator =
345               new MediaLocator ( saveFile.toURL() );
346
347            // create DataSink from output data source
348            // and user-specified save destination file
349            dataSink = Manager.createDataSink(
350               outSource, saveLocator );
351
```

Fig. 22.2 Formatting and saving media from capture devices (part 7 of 9).

```
352          // register a DataSinkListener for DataSinkEvents
353          dataSink.addDataSinkListener(
354
355             // anonymous inner class to handle DataSinkEvents
356             new DataSinkListener () {
357
358                // if end of media, close data writer
359                public void dataSinkUpdate(
360                   DataSinkEvent dataEvent )
361                {
362                   // if capturing stopped, close DataSink
363                   if ( dataEvent instanceof EndOfStreamEvent )
364                      dataSink.close();
365                }
366
367             }  // end DataSinkListener
368
369          ); // end call to method addDataSinkListener
370
371          // start saving
372          dataSink.open();
373          dataSink.start();
374
375       }  // end try
376
377       // DataSink could not be found for specific
378       // save file and data source
379       catch ( NoDataSinkException noDataSinkException ) {
380          noDataSinkException.printStackTrace();
381          return false;
382       }
383
384       // violation while accessing MediaLocator
385       // destination
386       catch ( SecurityException securityException ) {
387          securityException.printStackTrace();
388          return false;
389       }
390
391       // problem opening and starting DataSink
392       catch ( IOException ioException ) {
393          ioException.printStackTrace();
394          return false;
395       }
396
397       return true;
398
399    }  // end method makeDataWriter
400
401    // main method
402    public static void main( String args[] )
403    {
404       CapturePlayer testPlayer = new CapturePlayer();
```

Fig. 22.2 Formatting and saving media from capture devices (part 8 of 9).

```
405
406         testPlayer.setSize( 200, 70 );
407         testPlayer.setLocation( 300, 300 );
408         testPlayer.setDefaultCloseOperation( EXIT_ON_CLOSE );
409         testPlayer.setVisible( true );
410      }
411
412   }  // end class CapturePlayer
```

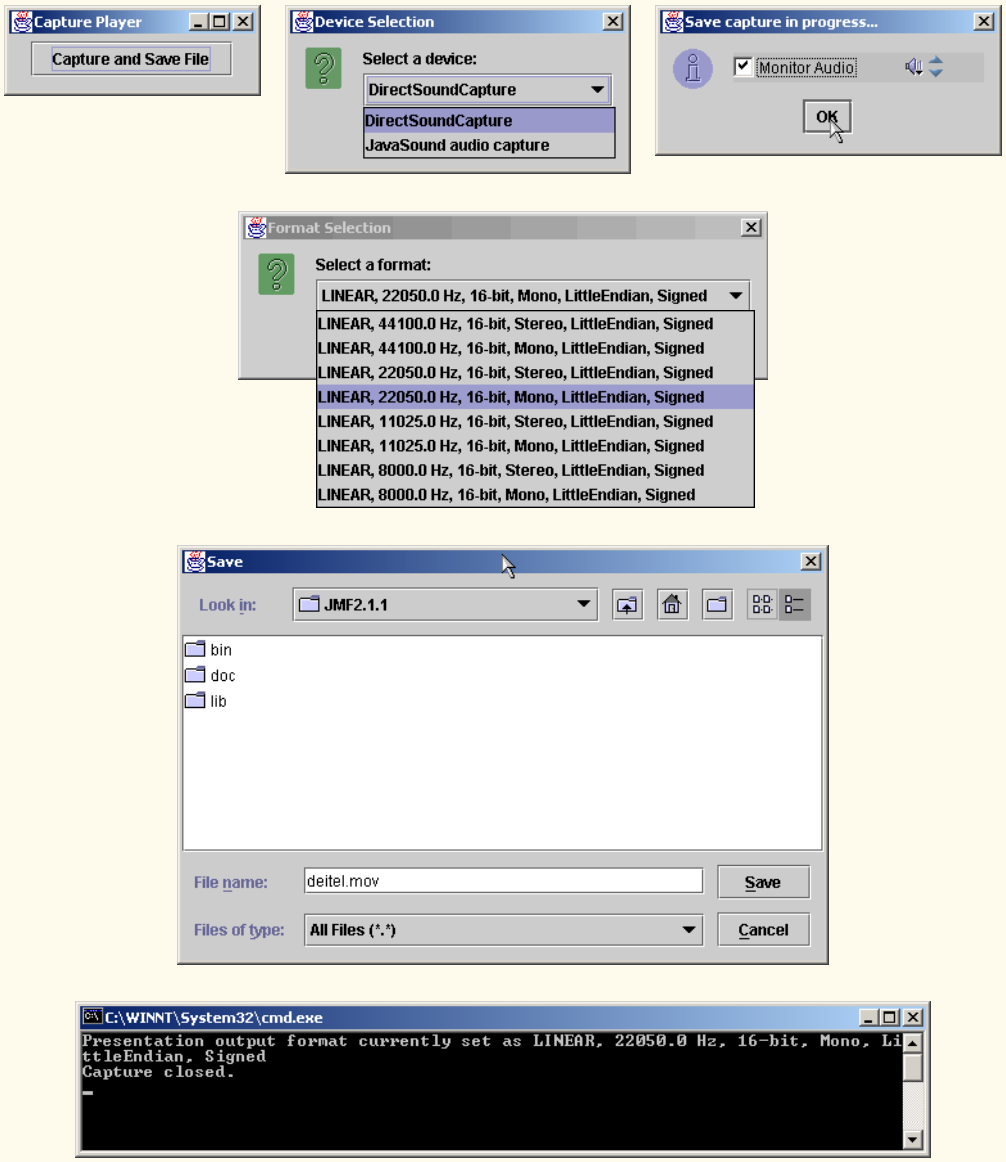

Fig. 22.2 Formatting and saving media from capture devices (part 9 of 9).

Class **CapturePlayer** (Fig. 22.2) illustrates capturing, setting media formats and saving media from capture devices supported by JMF. The simplest test of the program uses a microphone for audio input. Initially, the GUI has only one button, which users click to begin the configuration process. Users then select a capture device from a pull-down menu dialog. The next dialog box has options for the format of the capture device and file output. The third dialog box asks users to save the media to a specific file. The final dialog box provides a volume control and the option of monitoring the data. Monitoring allows users to hear or see the media as it is captured and saved without modifying it in any way. Many media capture technologies offer monitoring capabilities. For example, many video recorders have a screen attachment to let users see what the camera is capturing without looking through the viewfinder. In a recording studio producers can listen to live music being recorded through headphones in another room. Monitoring data is different from playing data in that it does not make any changes to the format of the media or affect the data being sent to the **Processor**.

In the **CapturePlayer** program, lines 14–16 import the JMF Java extension packages ***javax.media.protocol***, ***javax.media.format*** and ***javax.media.control***, which contain classes and interfaces for media control and device formatting. Line 17 imports the JMF package ***javax.media.datasink***, which contains classes for outputting formatted media. The program uses the classes and interfaces provided by these packages to obtain the desired capture device information, set the format of the capture device, create a **Processor** to handle the captured media data, create a ***DataSink*** to write the media data to a file and monitor the saving process.

CapturePlayer is capable of setting the media format. JMF provides class ***Format*** to describe the attributes of a media format, such as the *sampling rate* (which controls the quality of the sound) or whether the media should be in *stereo* or *mono* format. Each media format is encoded differently and can be played only with a media handler that supports its particular format. Line 28 declares an array of the **Format**s that the capture device supports and a **Format** reference for the user-selected format (**selectedFormat**).

After obtaining the **Format** objects, the program needs access to the formatting controls of the capture device. Line 31 declares an array to hold the ***FormatControl***s which will set the capture-device format. Class **CapturePlayer** sets the desired **Format** for the media source through the device's **FormatControl**s (line 31). The ***CaptureDeviceInfo*** reference **deviceInfo** (line 34) stores the capture device information, which will be placed in a **Vector** containing all of the device's information.

Class **DataSource** connects programs to media data sources, such as capture devices. The **SimplePlayer** of Figure 22.1 accessed a **DataSource** object by invoking **Manager** method **createPlayer**, passing in a **MediaLocator**. However, class **CapturePlayer** accesses the **DataSource** directly. Line 40 declares two **DataSource**s—**inSource** connects to the capture device's media and **outSource** connects to the output data source to which the captured media will be saved.

An object that implements interface **Processor** provides the primary function that controls and processes the flow of media data in class **CapturePlayer** (line 46). The class also creates an object that implements interface **DataSink** to write the captured data to a file (line 43).

Clicking the **Capture and Save File** button configures the capture device by invoking method **actionPerformed** (lines 93–171) in **private** inner class **Cap-**

tureHandler (lines 90–173). An instance of inner class **CaptureHandler** is registered to listen for **ActionEvent**s from **captureButton** (line 62). The program provides users with a list of available capture devices when lines 96–97 invoke ***CaptureDeviceManager*** **static** method ***getDeviceList***. Method **getDeviceList** obtains all of the computer's available devices that support the specified **Format**. Specifying **null** as the **Format** parameter returns a complete list of available devices. Class **CaptureDeviceManager** enables a program to access this list of devices.

Lines 109–119 copy the names of all capture devices into a **String** array (**deviceNames**) for display purposes. Lines 122-123 invoke **CapturePlayer** method **getSelectedDeviceIndex** (lines 195–210) to show a selector dialog with a list of all the device names stored in array **deviceNames**. The method call to **showInputDialog** (lines 198–201) has a different parameter list than earlier examples. The first four parameters are the dialog's parent component, message, title, and message type, as earlier chapters use. The final three, which are new, specify the icon (in this case, **null**), the list of values presented to the user (**deviceNames**), and the default selection (the first element of **deviceNames**). Once users select a device, the dialog returns the string, which is used to return the integer index of the selected name in **deviceNames**. This **String** helps determine the parallel element in the **deviceList**. This element, which is an instance of ***CaptureDeviceInfo***, creates and configures a new device from which the desired media can be recorded.

A **CaptureDeviceInfo** object encapsulates the information that the program needs to access and configure a capture device, such as location and format preferences. Calling methods ***getLocator*** (line 143) and ***getFormats*** (line 132) access these pieces of information. Lines 129–130 access the new **CaptureDeviceInfo** that the user specified in the **deviceList**. Next, lines 135–136 call **inSource**'s ***disconnect*** method to disengage any previously opened capture devices before connecting the new device.

Lines 142–143 invoke **Manager** method ***createDataSource*** to obtain the **DataSource** object that connects to the capture device's media source, passing in the capture device's **MediaLocator** object as an argument. **CaptureDeviceInfo** method **getLocator** returns the capture device's **MediaLocator**. Method **createDataSource** in turn invokes **DataSource** method ***connect*** which establishes a connection with the capture device. Method **createDataSource** throws a ***NoDataSourceException*** if it cannot locate a **DataSource** for the capture device. An **IOException** occurs if there is an error opening the device.

Before capturing the media, the program needs to format the **DataSource** as specified by the user in the Format Selection dialog. Lines 146–147 use ***CaptureDevice*** method ***getFormatControls*** to obtain an array of ***FormatControl***s for **DataSource inSource**. An object that implements interface **FormatControl** specifies the format of the **DataSource**. **DataSource** objects can represent media sources other than capture devices, so for this example the cast operator in line 146 manipulates object **inSource** as a **CaptureDevice** and accesses capture device methods such as **getFormatControls**. Line 150 invokes method **getSelectedFormat** (lines 213–219) to display an input dialog from which users can select one of the available formats. Lines 176–192 call the method **setDeviceFormat** to set the media output format for the device to the user-selected **Format**. Each capture device can have several **FormatControl**s, so **setDeviceFormat** uses **FormatControl** method **setFormat** to specify the format for each **FormatControl** object.

Formatting the **DataSource** completes the configuration of the capture device. A **Processor** (object **inSource**) converts the data to the file format in which it will be saved. The **Processor** works as a connector between the **outSource** and method **captureSaveFile** since **DataSource inSource** does not play or save the media, it only serves to configure the capture device. Line 157 invokes method **captureSaveFile** (lines 265–322) to perform the steps needed to save the captured media in a recognizable file format.

To create a **Processor**, this program first creates a ***ProcessorModel***, a template for the **Processor**. The **ProcessorModel** determines the attributes of a **Processor** through a collection of information which includes a **DataSource** or **MediaLocator**, the desired formats for the media tracks which the **Processor** will handle, and a ***ContentDescriptor*** indicating the output content type. Line 268 creates a new **Format** array (**outFormats**) that represents the possible formats for each track in the media. Line 270 sets the default format to the first element of the array. To save the captured output to a file, the **Processor** must first convert the data it receives to a file-enabled format. A new QuickTime ***FileTypeDescriptor*** (package **javax.media.format**) is created to store a description of the content type of the **Processor**'s output and store it in **outFileType** (lines 273–274). Lines 282–284 use the **DataSource inSource**, the array **outFormats**, and the file type **outFileType** to instantiate a new ***ProcessorModel*** (lines 283–284).

Generally, **Processor**s need to be configured before they can process media, but the one in this application does not since lines 282–284 invoke **Manager** method ***createRealizedProcessor***. This method creates a configured, realized **Processor** based on the **ProcessorModel** object passed in as an argument. Method **createRealizedProcessor** throws a ***NoProcessorException*** if the program cannot locate a **Processor** for the media or if JMF does not support the media type. The method throws a ***CannotRealizeException*** if the **Processor** cannot be realized. This may occur if another program is already using the media, thus blocking communication with the media source.

Common Programming Error 22.1

Be careful when specifying track formats. Incompatible formats for specific output file types prevent the program from realizing the ***Processor****.*

Software Engineering Observation 22.2

Recall that the ***Processor*** *transitions through several states before being realized.* ***Manager*** *method* ***createProcessor*** *allows a program to provide more customized configuration before a* ***Processor*** *is realized.*

Performance Tip 22.2

When method ***createRealizedProcessor*** *configures the* ***Processor****, the method blocks until the* ***Processor*** *is realized. This may prevent other parts of the program from executing. In some cases, using a* ***ControllerListener*** *to respond to* ***ControllerEvent****s may enable a program to operate more efficiently. When the* ***Processor*** *is realized, the listener is notified so the program can begin processing the media.*

Having obtained media data in a file format from the **Processor**, the program can make a "data writer" to write the media output to a file. An object that implements interface **DataSink** enables media data to be output to a specific location—most commonly a file.

Line 287 invokes method **makeDataWriter** (lines 325–399) to create a **DataSink** object that can save the file. **Manager** method ***createDataSink*** requires the **DataSource** of the **Processor** and the **MediaLocator** for the new file as arguments. Within **makeDataWriter**, lines 229–242 invokes method **getSaveFile** to prompt users to specify the name and location of the file to which the media should be saved. The **File** object **saveFile** stores the information. **Processor** method ***getDataOutput*** (line 333) returns the **DataSource** from which it received the media. Lines 344–345 create a new **MediaLocator** for **saveFile**. Using this **MediaLocator** and the **DataSource**, lines 349–350 create a **DataSink** object which writes the output media from the **DataSource** to the file in which the data will be saved, as specified by the **MediaLocator**. Method **createDataSink** throws a ***NoDataSinkException*** if it cannot create a **DataSink** that can read data from the **DataSource** and output the data to the location specified by the **MediaLocator**. This failure may occur as a result of invalid media or an invalid **MediaLocator**.

The program needs to know when to stop outputting data, so lines 353–369 register a ***DataSinkListener*** to listen for ***DataSinkEvent***s. **DataSinkListener** method ***dataSinkUpdate*** (lines 359–365) is called when each **DataSinkEvent** occurs. If the **DataSinkEvent** is an ***EndOfStreamEvent***, indicating that the **Processor** has been closed because the capture stream connection has closed, line 364 closes the **DataSink**. Invoking **DataSink** method ***close*** stops the data transfer. A closed **DataSink** cannot be used again.

Common Programming Error 22.2

*The media file output with a **DataSink** will be corrupted if the **DataSink** is not closed properly.*

Software Engineering Observation 22.3

*Captured media may not yield an **EndOfMediaEvent** if the media's endpoint cannot be determined.*

After setting up the **DataSink** and registering its listener, line 372 calls **DataSink** method ***open*** to connect the **DataSink** to the destination that the **MediaLocator** specifies. Method **open** throws a ***SecurityException*** if the **DataSink** attempts to write to a destination for which the program does not have write permission, such as a read-only file.

Line 373 calls **DataSink** method ***start*** to initiate data transfer. At this point, the program returns from method **makeDataWriter** back to method **captureSaveFile** (lines 265–322). Although the **DataSink** prepares itself to receive the transfer and indicates that it is ready by calling **start**, the transfer does not actually take place until the **Processor**'s ***start*** method is called. The invocation of **Processor** method **start** begins the flow of data from the capture device, formats the data and transfers that data to the **DataSink**. The **DataSink** writes the media to a file, which completes the process performed by class **CapturePlayer**.

While **Processor** encodes the data and the **DataSink** saves it to a file, **CapturePlayer** *monitors* the process. Monitoring provides a method of overseeing data as the capture device collects it. Lines 294–296 obtain an object that implements interface ***MonitorControl*** (package **javax.media.control**) from the **Processor** by calling method ***getControl***. Line 299 calls **MonitorControl** method ***getControlCom-***

`ponent` to obtain the GUI component that displays the monitored media. **`MonitorControl`**s typically have a checkbox to enable or disable displaying media. Also, audio devices have a volume control and video devices have a control for setting the *preview frame rate*. Line 301 invokes method **`showSaveMonitor`** (lines 245–261) to display the monitoring GUI in a dialog box. To terminate capturing, users can press the **OK** button or close the dialog box (lines 254–261). For some video capture devices, the **`Processor`** needs to be in a *Stopped* state to enable monitoring of the saving and capturing process.

Thus far, we have discussed JMF's capabilities to access, present and save media content. Our final JMF example demonstrates how to send media between computers using JMF's *streaming* capabilities.

22.4 RTP Streaming

Streaming media refers to media that is transferred from a server to a client in a continuous stream of bytes. The client can begin playing the media while still downloading the media from the server. Audio and video media files are often many megabytes in size. Live events, such as concerts or football game broadcasts, may have indeterminable sizes. Users could wait until a recording of a concert or game is posted, then download the entire recording. However, at today's Internet connection speeds, downloading such a broadcast could take days and typically users prefer to listen to live broadcasts as they occur. Streaming media enables client applications to play media over the Internet or over a network without downloading the entire media file at once.

In a streaming media application, the client typically connects to a server that sends a stream of bytes containing the media back to the client. The client application *buffers* (i.e. stores locally) a portion of the media, which the client begins playing after a certain portion has been received. The client continually buffers additional media, providing users with an uninterrupted clip, as long as network traffic does not prevent the client application from buffering additional bytes. With buffering, users experience the media within seconds of when the streaming begins, even though all of the material has not been received.

Performance Tip 22.3

Streaming media to a client enables the client to experience the media faster than if the client must wait for an entire media file to download.

Demand for real-time, robust multimedia is rising dramatically as the speed of Internet connections increase. *Broadband Internet access,* which provides high-speed network connections to the Internet for so many home users, is becoming more popular, though the number of users remains relatively small compared to the total number of Internet users. With faster connections, streaming media can provide a better multimedia experience. Users with slower connections can still experience the multimedia, though with lesser quality. The wide range of applications that use streaming media is growing. Applications that stream video clips to clients have expanded to provide real-time broadcast feeds. Thousands of radio stations stream music continuously over the Internet. Client applications such as RealPlayer have focused on streaming media content with live radio broadcasts. Applications are not limited to audio and video server-to-client streaming. For example, teleconferencing and video conferencing applications increase efficiency in everyday business by reducing the need for business people to travel great distances to attend meetings.

JMF provides a streaming media package that enables Java applications to send and receive streams of media in some of the formats discussed earlier in this chapter. For a complete list of formats, see the official JMF Web site:

java.sun.com/products/java-media/jmf/2.1.1/formats.html

JMF uses the industry-standard *Real-Time Transport Protocol* (*RTP*) to control media transmission. RTP is designed specifically to transmit real-time media data.

The two mechanisms for streaming RTP-supported media are passing it through a **DataSink** and buffering it. The easier mechanism to use is a **DataSink**, which writes the contents of a stream to a host destination (i.e., a client computer), via the same techniques shown in Fig. 22.2 to save captured media to a file. In this case, however, the destination **MediaLocator**'s URL would be specified in the following format:

rtp://*host*:*port*/*contentType*

where *host* is the IP address or host name of the server, *port* is the port number on which the server is streaming the media and *contentType* is either **audio** or **video**.

Using a **DataSink** as specified allows only one stream to be sent at a time. To send multiple streams (e.g., as a karaoke video with separate tracks for video and audio would) to multiple hosts, a server application must use *RTP session managers*. An ***RTPManager*** (package **javax.media.rtp**) provides more control over the streaming process, permitting specification of buffer sizes, error checking and streaming reports on the *propagation delay* (the time it takes for the data to reach its destination).

The program in Fig. 22.3 and Fig. 22.4 demonstrates streaming using the RTP session manager. This example supports sending multiple streams in parallel, so separate clients must be opened for each stream. This example does not show a client that can receive the RTP stream. The program in Fig. 22.1 (**SimplePlayer**) can test the RTP server by specifying an RTP session address

rtp://127.0.0.1:4000/audio

as the location **SimplePlayer** should open to begin playing audio. To execute the streaming media server on a different computer, replace **127.0.0.1** with either the IP address or host name of the server computer.

```
1  // Fig. 22.3: RTPServer.java
2  // Provides configuration and sending capabilities
3  // for RTP-supported media files
4
5  // Java core packages
6  import java.io.*;
7  import java.net.*;
8
9  // Java extension packages
10 import javax.media.*;
11 import javax.media.protocol.*;
12 import javax.media.control.*;
13 import javax.media.rtp.*;
14 import javax.media.format.*;
```

Fig. 22.3 Serving streaming media with RTP session managers (part 1 of 7).

```
15
16 public class RTPServer {
17
18    // IP address, file or medialocator name, port number
19    private String ipAddress, fileName;
20    private int port;
21
22    // processor controlling data flow
23    private Processor processor;
24
25    // data output from processor to be sent
26    private DataSource outSource;
27
28    // media tracks' configurable controls
29    private TrackControl tracks[];
30
31    // RTP session manager
32    private RTPManager rtpManager[];
33
34    // constructor for RTPServer
35    public RTPServer( String locator, String ip, int portNumber )
36    {
37       fileName = locator;
38       port = portNumber;
39       ipAddress = ip;
40    }
41
42    // initialize and set up processor
43    // return true if successful, false if not
44    public boolean beginSession()
45    {
46       // get MediaLocator from specific location
47       MediaLocator mediaLocator = new MediaLocator( fileName );
48
49       if ( mediaLocator == null ) {
50          System.err.println(
51             "No MediaLocator found for " + fileName );
52
53          return false;
54       }
55
56       // create processor from MediaLocator
57       try {
58          processor = Manager.createProcessor( mediaLocator );
59
60          // register a ControllerListener for processor
61          // to listen for state and transition events
62          processor.addControllerListener(
63             new ProcessorEventHandler() );
64
65          System.out.println( "Processor configuring..." );
66
```

Fig. 22.3 Serving streaming media with RTP session managers (part 2 of 7).

```
67             // configure processor before setting it up
68             processor.configure();
69          }
70
71          // source connection error
72          catch ( IOException ioException ) {
73             ioException.printStackTrace();
74             return false;
75          }
76
77          // exception thrown when no processor could
78          // be found for specific data source
79          catch ( NoProcessorException noProcessorException ) {
80             noProcessorException.printStackTrace();
81             return false;
82          }
83
84          return true;
85
86       }  // end method beginSession
87
88       // ControllerListener handler for processor
89       private class ProcessorEventHandler
90          extends ControllerAdapter {
91
92          // set output format and realize
93          // configured processor
94          public void configureComplete(
95             ConfigureCompleteEvent configureCompleteEvent )
96          {
97             System.out.println( "\nProcessor configured." );
98
99             setOutputFormat();
100
101            System.out.println( "\nRealizing Processor...\n" );
102
103            processor.realize();
104         }
105
106         // start sending when processor is realized
107         public void realizeComplete(
108            RealizeCompleteEvent realizeCompleteEvent )
109         {
110            System.out.println(
111               "\nInitialization successful for " + fileName );
112
113            if ( transmitMedia() == true )
114               System.out.println( "\nTransmission setup OK" );
115
116            else
117               System.out.println( "\nTransmission failed." );
118         }
119
```

Fig. 22.3 Serving streaming media with RTP session managers (part 3 of 7).

```
120         // stop RTP session when there is no media to send
121         public void endOfMedia( EndOfMediaEvent mediaEndEvent )
122         {
123             stopTransmission();
124             System.out.println ( "Transmission completed." );
125         }
126
127      }  // end inner class ProcessorEventHandler
128
129      // set output format of all tracks in media
130      public void setOutputFormat()
131      {
132         // set output content type to RTP capable format
133         processor.setContentDescriptor(
134            new ContentDescriptor( ContentDescriptor.RAW_RTP ) );
135
136         // get all track controls of processor
137         tracks = processor.getTrackControls();
138
139         // supported RTP formats of a track
140         Format rtpFormats[];
141
142         // set each track to first supported RTP format
143         // found in that track
144         for ( int i = 0; i < tracks.length; i++ ) {
145
146            System.out.println( "\nTrack #" +
147               ( i + 1 ) +   " supports " );
148
149            if ( tracks[ i ].isEnabled() ) {
150
151               rtpFormats = tracks[ i ].getSupportedFormats();
152
153               // if supported formats of track exist,
154               // display all supported RTP formats and set
155               // track format to be first supported format
156               if ( rtpFormats.length > 0 ) {
157
158                  for ( int j = 0; j < rtpFormats.length; j++ )
159                     System.out.println( rtpFormats[ j ] );
160
161                  tracks[ i ].setFormat( rtpFormats[ 0 ] );
162
163                  System.out.println ( "Track format set to " +
164                     tracks[ i ].getFormat() );
165               }
166
167               else
168                  System.err.println (
169                     "No supported RTP formats for track!" );
170
171            }  // end if
172
```

Fig. 22.3 Serving streaming media with RTP session managers (part 4 of 7).

```
173         }  // end for loop
174
175      }  // end method setOutputFormat
176
177      // send media with boolean success value
178      public boolean transmitMedia()
179      {
180         outSource = processor.getDataOutput();
181
182         if ( outSource == null ) {
183            System.out.println ( "No data source from media!" );
184
185            return false;
186         }
187
188         // rtp stream managers for each track
189         rtpManager = new RTPManager[ tracks.length ];
190
191         // destination and local RTP session addresses
192         SessionAddress localAddress, remoteAddress;
193
194         // RTP stream being sent
195         SendStream sendStream;
196
197         // IP address
198         InetAddress ip;
199
200         // initialize transmission addresses and send out media
201         try {
202
203            // transmit every track in media
204            for ( int i = 0; i < tracks.length; i++ ) {
205
206               // instantiate a RTPManager
207               rtpManager[ i ] = RTPManager.newInstance();
208
209               // add 2 to specify next control port number;
210               // (RTP Session Manager uses 2 ports)
211               port += ( 2 * i );
212
213               // get IP address of host from ipAddress string
214               ip = InetAddress.getByName( ipAddress );
215
216               // encapsulate pair of IP addresses for control and
217               // data with 2 ports into local session address
218               localAddress = new SessionAddress(
219                  ip.getLocalHost(), port );
220
221               // get remoteAddress session address
222               remoteAddress = new SessionAddress( ip, port );
223
224               // initialize the session
225               rtpManager[ i ].initialize( localAddress );
```

Fig. 22.3 Serving streaming media with RTP session managers (part 5 of 7).

```
226
227             // open RTP session for destination
228             rtpManager[ i ].addTarget( remoteAddress );
229
230             System.out.println( "\nStarted RTP session: "
231                + ipAddress + " " + port);
232
233             // create send stream in RTP session
234             sendStream =
235                rtpManager[ i ].createSendStream( outSource, i );
236
237             // start sending the stream
238             sendStream.start();
239
240             System.out.println( "Transmitting Track #" +
241                ( i + 1 ) + " ... " );
242
243          }  // end for loop
244
245          // start media feed
246          processor.start();
247
248       }  // end try
249
250       // unknown local or unresolvable remote address
251       catch ( InvalidSessionAddressException addressError ) {
252          addressError.printStackTrace();
253          return false;
254       }
255
256       // DataSource connection error
257       catch ( IOException ioException ) {
258          ioException.printStackTrace();
259          return false;
260       }
261
262       // format not set or invalid format set on stream source
263       catch ( UnsupportedFormatException formatException ) {
264          formatException.printStackTrace();
265          return false;
266       }
267
268       // transmission initialized successfully
269       return true;
270
271    }  // end method transmitMedia
272
273    // stop transmission and close resources
274    public void stopTransmission()
275    {
276       if ( processor != null ) {
277
```

Fig. 22.3 Serving streaming media with RTP session managers (part 6 of 7).

```
278            // stop processor
279            processor.stop();
280
281            // dispose processor
282            processor.close();
283
284            if ( rtpManager != null )
285
286               // close destination targets
287               // and dispose RTP managers
288               for ( int i = 0; i < rtpManager.length; i++ ) {
289
290                  // close streams to all destinations
291                  // with a reason for termination
292                  rtpManager[ i ].removeTargets(
293                     "Session stopped." );
294
295                  // release RTP session resources
296                  rtpManager[ i ].dispose();
297               }
298
299         }  // end if
300
301         System.out.println ( "Transmission stopped." );
302
303      }  // end method stopTransmission
304
305   }  // end class RTPServer
```

Fig. 22.3 Serving streaming media with RTP session managers (part 7 of 7).

Class **RTPServer**'s purpose is to stream media content. As in previous examples, the **RTPServer** (Fig. 22.3) sets up the media, processes and formats it, then outputs it. **ControllerEvent**s and the various states of the streaming process drive this process. Processing of the media has three distinct parts—**Processor** initialization, **Format** configuration and data transmission. The code in this example contains numerous confirmation messages displayed to the command prompt and an emphasis on error checking. A problem during streaming will most likely end the entire process and it will need to be restarted.

To test **RTPServer**, class **RTPServerTest** (Fig. 22.4) creates a new **RTPServer** object and passes its constructor (lines 35–40) three arguments—a **String** representing the media's location, a **String** representing the IP address of the client and a port number for streaming content. These arguments contain the information class **RTPServer** needs to obtain the media and set up the streaming process. Following the general approach outlined in **SimplePlayer** (Fig. 22.1) and **CapturePlayer** (Fig. 22.2), class **RTPServer** obtains a media source, configures the source through a type of **Controller** and outputs the data to a specified destination.

RTPServerTest calls **RTPServer** method **beginSession** (lines 44–86) to set up the **Processor** that controls the data flow. Line 47 creates a **MediaLocator** and initializes it with the media location stored in **fileName**. Line 58 creates a **Processor** for the data specified by that **MediaLocator**.

Unlike the program in Fig. 22.2, this **Processor** is not preconfigured by a **Manager**. Until class **RTPServer** configures and realizes the **Processor**, the media cannot be formatted. Lines 62–63 register a **ProcessorEventHandler** to react to the **processor**'s **ControllerEvent**s. The methods of class **ProcessorEventHandler** (lines 89–127) control the media setup as the **Processor** changes states. Line 68 invokes **Processor** method ***configure*** to place the **Processor** in the *Configuring* state. Configuration is when the **Processor** inquires of the system and the media the format information needed to program the **Processor** to perform the correct task. A ***ConfigureCompleteEvent*** occurs when the **Processor** completes configuration. The **ProcessorEventHandler** method ***configureComplete*** (lines 94–104) responds to this transition. Method **configureComplete** calls method **setOutputFormat** (lines 130–175) then realizes the **Processor** (line 103). When line 99 invokes method **setOutputFormat**, it sets each media track to an RTP streaming media format. Lines 133–134 in method **setOutputFormat** specify the output content-type by calling **Processor** method ***setContentDescriptor***. The method takes as an argument a **ContentDescriptor** initialized with constant **ContentDescriptor.RAW_RTP**. The RTP output content-type restricts the **Processor** to only support RTP-enabled media track formats. The **Processor**'s output content-type should be set before the media tracks are configured.

Once the **Processor** is configured, the media track formats need to be set. Line 137 invokes **Processor** method ***getTrackControls*** to obtain an array that contains the corresponding ***TrackControl*** object (package **javax.media.control**) for each media track. For each enabled **TrackControl**, lines 144–173 obtain an array of all supported RTP media **Format**s (line 151), then set the first supported RTP format as the preferred RTP-streaming media format for that track (line 161). When method **setOutputFormat** returns, line 103 in method **configureComplete** realizes the **Processor**.

As with any controller realization, the **Processor** can output media as soon as it has finished realizing itself. When the **Processor** enters the *Realized* state, the **ProcessorEventHandler** invokes method **realizeComplete** (lines 107–118). Line 113 invokes method **transmitMedia** (lines 178–271) which creates the structures needed to transmit the media to the **Processor**. This method obtains the **DataSource** from the **Processor** (line 180), then declares an array of ***RTPManager***s that are able to start and control an RTP session (line 189). **RTPManager**s use a pair of **SessionAddress** objects with identical IP addresses, but different port numbers—one for stream control and one for streaming media data. An **RTPManager** receives each IP address and port number as a ***SessionAddress*** object. Line 192 declares the **SessionAddress** objects used in the streaming process. An object that implements interface ***SendStream*** (line 195) performs the RTP streaming.

Software Engineering Observation 22.4

For videos that have multiple tracks, each ***SendStream*** *must have its own* ***RTPManager*** *managing its session. Each* ***Track*** *has its own* ***SendStream****.*

The try block (lines 201–248) of method **transmitMedia** sends out each track of the media as an RTP stream. First, managers must be created for the sessions. Line 207 invokes **RTPManager** method ***newInstance*** to instantiate an **RTPManager** for each

track stream. Line 211 assigns the port number to be two more than the previous port number, because the each track uses one port number for the stream control and one to actually stream the data. Lines 218–219 instantiate a new local session address where the stream is located (i.e., the RTP address that clients use to obtain the media stream) with the local IP address and a port number as parameters. Line 219 invokes **`InetAddress`** method **`getLocalHost`** to get the local IP address. Line 222 instantiates the client's session address, which the **`RTPManager`** uses as the stream's target destination. When line 225 calls **`RTPManager`** method ***`initialize`***, the method directs the local streaming session to use the local session address. Using object **`remoteAddress`** as a parameter, line 228 calls **`RTPManager`** method ***`addTarget`*** to open the destination session at the specified address. To stream media to multiple clients, call **`RTPManager`** method **`addTarget`** for each destination address. Method **`addTarget`** must be called after the session is initialized and before any of the streams are created on the session.

The program can now create the streams on the session and start sending data. The streams are created in the current RTP session with the **`DataSource outSource`** (obtained at line 180) and the source stream index (i.e. media track index) in lines 234–235. Invoking method **`start`** on the **`SendStream`** (line 238) and on the **`Processor`** (line 246) starts transmission of the media streams, which may cause exceptions. An ***`InvalidSessionAddressException`*** occurs when the specified session address is invalid. An ***`UnsupportedFormatException`*** occurs when an unsupported media format is specified or if the **`DataSource`**'s **`Format`** has not been set. An **`IOException`** occurs if the application encounters networking problems. During the streaming process, **`RTPManager`**s can be used with related classes in package **`javax.media.rtp`** and package **`javax.media.rtp.event`** controls the streaming process and send reports to the application.

The program should close connections and stop streaming transmission when it reaches the end of the streaming media or when the program terminates. When the **`Processor`** encounters the end of the media, it generates an **`EndOfMediaEvent`**. In response, the program calls method **`endOfMedia`** (lines 121–125). Line 123 invokes method **`stopTransmission`** (lines 274–303) to stop and close the **`Processor`** (lines 279–282). After calling **`stopTransmission`**, streaming cannot resume because it disposes of the **`Processor`** and the RTP session resources. Lines 288–297 invoke **`RTPManager`** method ***`removeTargets`*** (lines 292–293) to close streaming to all destinations. **`RTPManager`** method ***`dispose`*** (line 296) is also invoked, releasing the resources held by the RTP sessions. The class **`RTPServerTest`** (Fig. 22.4), explicitly invokes method **`stopTransmission`** when users terminates the server application (line 40).

```
1  // Fig. 22.4: RTPServerTest.java
2  // Test class for RTPServer
3
4  // Java core packages
5  import java.awt.event.*;
6  import java.io.*;
7  import java.net.*;
8
```

Fig. 22.4 Application to test class **`RTPServer`** from Fig. 22.3 (part 1 of 6).

```
 9  // Java extension packages
10  import javax.swing.*;
11
12  public class RTPServerTest extends JFrame {
13
14     // object handling RTP streaming
15     private RTPServer rtpServer;
16
17     // media sources and destination locations
18     private int port;
19     private String ip, mediaLocation;
20     private File mediaFile;
21
22     // GUI buttons
23     private JButton transmitFileButton, transmitUrlButton;
24
25     // constructor for RTPServerTest
26     public RTPServerTest()
27     {
28        super( "RTP Server Test" );
29
30        // register a WindowListener for frame events
31        addWindowListener(
32
33           // anonymous inner class to handle WindowEvents
34           new WindowAdapter() {
35
36              public void windowClosing(
37                 WindowEvent windowEvent )
38              {
39                 if ( rtpServer != null )
40                    rtpServer.stopTransmission();
41              }
42
43           }  // end WindowAdpater
44
45        ); // end call to method addWindowListener
46
47        // panel containing button GUI
48        JPanel buttonPanel = new JPanel();
49        getContentPane().add( buttonPanel );
50
51        // transmit file button GUI
52        transmitFileButton = new JButton( "Transmit File" );
53        buttonPanel.add( transmitFileButton );
54
55        // register ActionListener for transmitFileButton events
56        transmitFileButton.addActionListener(
57           new ButtonHandler() );
58
59        // transmit URL button GUI
60        transmitUrlButton = new JButton( "Transmit Media" );
61        buttonPanel.add( transmitUrlButton );
```

Fig. 22.4 Application to test class **RTPServer** from Fig. 22.3 (part 2 of 6).

```
62
63          // register ActionListener for transmitURLButton events
64          transmitUrlButton.addActionListener(
65             new ButtonHandler() );
66
67       }  // end constructor
68
69       // inner class handles transmission button events
70       private class ButtonHandler implements ActionListener {
71
72          // open and try to send file to user-input destination
73          public void actionPerformed( ActionEvent actionEvent )
74          {
75             // if transmitFileButton invoked, get file URL string
76             if ( actionEvent.getSource() == transmitFileButton ) {
77
78                mediaFile = getFile();
79
80                if ( mediaFile != null )
81
82                   // obtain URL string from file
83                   try {
84                      mediaLocation = mediaFile.toURL().toString();
85                   }
86
87                   // file path unresolvable
88                   catch ( MalformedURLException badURL ) {
89                      badURL.printStackTrace();
90                   }
91
92                else
93                   return;
94
95             }  // end if
96
97             // else transmitMediaButton invoked, get location
98             else
99                mediaLocation = getMediaLocation();
100
101            if ( mediaLocation == null )
102               return;
103
104            // get IP address
105            ip = getIP();
106
107            if ( ip == null )
108               return;
109
110            // get port number
111            port = getPort();
112
```

Fig. 22.4 Application to test class **RTPServer** from Fig. 22.3 (part 3 of 6).

```
113          // check for valid positive port number and input
114          if ( port <= 0 ) {
115
116             if ( port != -999 )
117                System.err.println( "Invalid port number!" );
118
119             return;
120          }
121
122          // instantiate new RTP streaming server
123          rtpServer = new RTPServer( mediaLocation, ip, port );
124
125          rtpServer.beginSession();
126
127       }  // end method actionPeformed
128
129    }  // end inner class ButtonHandler
130
131    // get file from computer
132    public File getFile()
133    {
134       JFileChooser fileChooser = new JFileChooser();
135
136       fileChooser.setFileSelectionMode(
137          JFileChooser.FILES_ONLY );
138
139       int result = fileChooser.showOpenDialog( this );
140
141       if ( result == JFileChooser.CANCEL_OPTION )
142          return null;
143
144       else
145          return fileChooser.getSelectedFile();
146    }
147
148    // get media location from user
149    public String getMediaLocation()
150    {
151       String input = JOptionPane.showInputDialog(
152          this, "Enter MediaLocator" );
153
154       // if user presses OK with no input
155       if ( input != null && input.length() == 0 ) {
156          System.err.println( "No input!" );
157          return null;
158       }
159
160       return input;
161    }
162
163    // method getting IP string from user
164    public String getIP()
165    {
```

Fig. 22.4 Application to test class **RTPServer** from Fig. 22.3 (part 4 of 6).

```
166         String input = JOptionPane.showInputDialog(
167            this, "Enter IP Address: " );
168
169         // if user presses OK with no input
170         if ( input != null && input.length() == 0 ) {
171            System.err.println( "No input!" );
172            return null;
173         }
174
175         return input;
176      }
177
178      // get port number
179      public int getPort()
180      {
181         String input = JOptionPane.showInputDialog(
182            this, "Enter Port Number: " );
183
184         // return flag value if user clicks OK with no input
185         if ( input != null && input.length() == 0 ) {
186            System.err.println( "No input!" );
187            return -999;
188         }
189
190         // return flag value if user clicked CANCEL
191         if ( input == null )
192            return -999;
193
194         // else return input
195         return Integer.parseInt( input );
196
197      }  // end method getPort
198
199      // execute application
200      public static void main( String args[] )
201      {
202         RTPServerTest serverTest = new RTPServerTest();
203
204         serverTest.setSize( 250, 70 );
205         serverTest.setLocation( 300, 300 );
206         serverTest.setDefaultCloseOperation( EXIT_ON_CLOSE );
207         serverTest.setVisible( true );
208      }
209
210   }  // end class RTPServerTest
```

Fig. 22.4 Application to test class **RTPServer** from Fig. 22.3 (part 5 of 6).

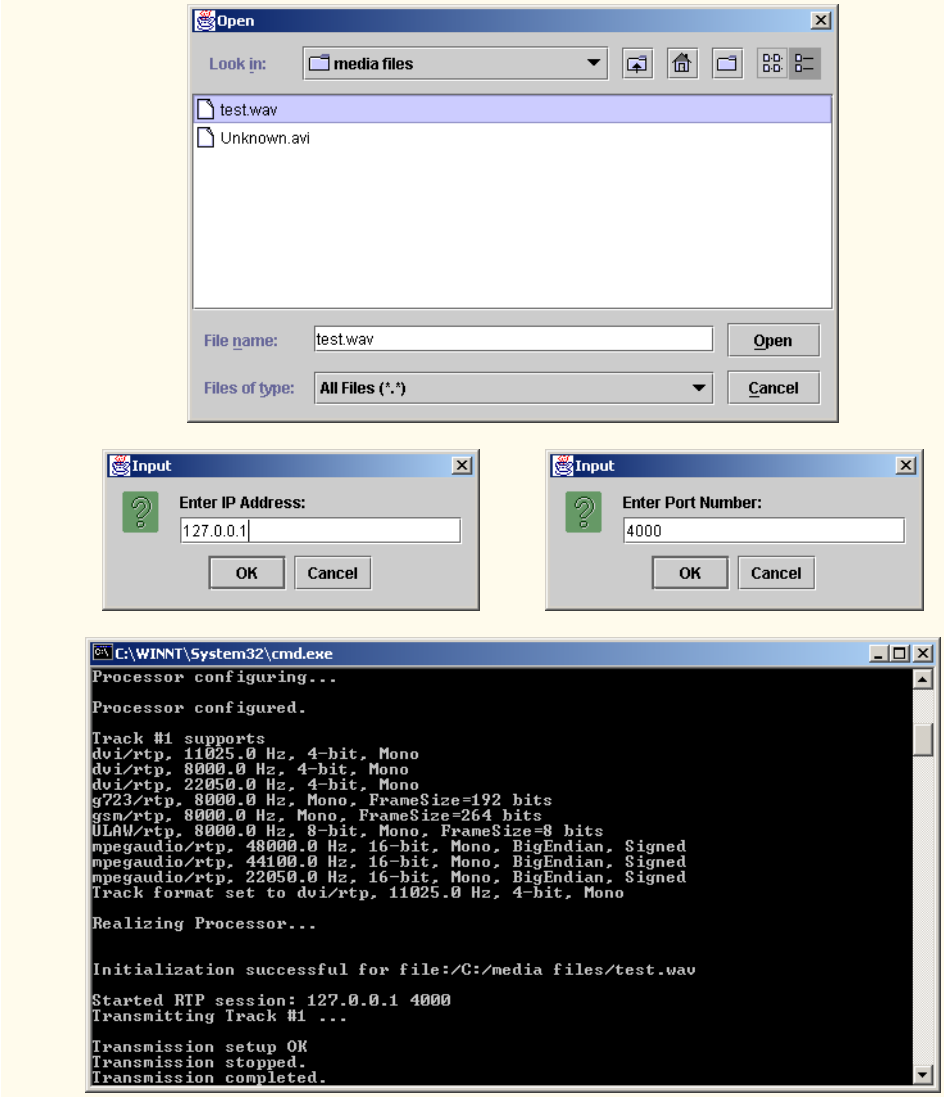

Fig. 22.4 Application to test class **`RTPServer`** from Fig. 22.3 (part 6 of 6).

22.5 Java Sound

Many of today's computer programs capture users' attention with audio features. Even basic applets and applications can enhance users' experiences with simple sounds or music clips. With sound programming interfaces, developers can create applications that play sounds in response to user interactions. For example, in many applications, when an error occurs and a dialog box appears on the screen, the dialog is often accompanied by a sound. Users thus receive both audio and visual indications that a problem has occurred. As another example, game programmers use extensive audio capabilities to enhance players' experiences.

The *Java Sound API* is a simpler way to incorporate audio media into applications than the Java Media Framework. The Java Sound API is bundled with Java 2 Software Development Kit version 1.3. The API consists of four packages—***javax.sound.midi***, ***javax.sound.midi.spi***, ***javax.sound.sampled*** and ***javax.sound.sampled.spi***. The next two sections focus on packages **javax.sound.midi** and **javax.sound.sampled**, which provide classes and interfaces for accessing, manipulating and playing *Musical Instrumental Data Interface* (*MIDI*) and sampled audio. The packages ending in **.spi** provide developers with the tools to add Java Sound support for additional audio formats that are beyond the scope of this book.

The Java Sound API provides access to the *Java Sound Engine* which creates digitized audio and captures media from the supported sound devices discussed in Section 22.3. Java Sound requires a sound card to play audio. A program using Java Sound will throw an exception if it accesses audio system resources on a computer that does not have a sound card.

22.6 Playing Sampled Audio

This section introduces the features of package **javax.sound.sampled** for playing sampled audio file formats, which include Sun Audio (**.au**), Windows Waveform (**.wav**) and Macintosh Audio Interchange File Format (**.aiff**). The program in Fig. 22.5 and Fig. 22.6 shows how audio is played using these file formats.

When processing audio data, a *line* provides the path through which audio flows in a system. One example of a line is a pair of headphones connected to a CD player.

Class **ClipPlayer** (Fig. 22.5) is an example of how lines can be used. It contains an object that implements interface ***Clip***, which in turn extends interface ***DataLine***. A **Clip** is a line that processes an entire audio file rather than reading continuously from an audio stream. **DataLine**s enhance **Line**s by providing additional methods (such as ***start*** and ***stop***) for controlling the flow of data, and **Clip**s enhance **DataLine**s by providing methods for opening **Clip**s and methods for precise control over playing and looping the audio.

```
1  // Fig. 22.5: ClipPlayer.java
2  // Plays sound clip files of type WAV, AU, AIFF
3
4  // Java core packages
5  import java.io.*;
6
7  // Java extension packages
8  import javax.sound.sampled.*;
9
10 public class ClipPlayer implements LineListener {
11
12    // audio input stream
13    private AudioInputStream soundStream;
14
15    // audio sample clip line
16    private Clip clip;
17
```

Fig. 22.5 **ClipPlayer** plays an audio file (part 1 of 4).

```
18      // Audio clip file
19      private File soundFile;
20
21      // boolean indicating replay of audio
22      private boolean replay = false;
23
24      // constructor for ClipPlayer
25      public ClipPlayer( File audioFile )
26      {
27         soundFile = audioFile;
28      }
29
30      // open music file, returning true if successful
31      public boolean openFile()
32      {
33         // get audio stream from file
34         try {
35            soundStream =
36               AudioSystem.getAudioInputStream( soundFile );
37         }
38
39         // audio file not supported by JavaSound
40         catch ( UnsupportedAudioFileException audioException ) {
41            audioException.printStackTrace();
42            return false;
43         }
44
45         // I/O error attempting to get stream
46         catch ( IOException ioException ) {
47            ioException.printStackTrace();
48            return false;
49         }
50
51         // invoke loadClip, returning true if load successful
52         return loadClip();
53
54      }  // end method openFile
55
56      // load sound clip
57      public boolean loadClip ()
58      {
59         // get clip line for file
60         try {
61
62            // get audio format of sound file
63            AudioFormat audioFormat = soundStream.getFormat();
64
65             // define line information based on line type,
66             // encoding and frame sizes of audio file
67            DataLine.Info dataLineInfo = new DataLine.Info(
68               Clip.class, AudioSystem.getTargetFormats(
69                  AudioFormat.Encoding.PCM_SIGNED, audioFormat ),
```

Fig. 22.5 **`ClipPlayer`** plays an audio file (part 2 of 4).

```
70                audioFormat.getFrameSize(),
71                audioFormat.getFrameSize() * 2 );
72
73             // make sure sound system supports data line
74             if ( !AudioSystem.isLineSupported( dataLineInfo ) ) {
75
76                System.err.println( "Unsupported Clip File!" );
77                return false;
78             }
79
80             // get clip line resource
81             clip = ( Clip ) AudioSystem.getLine( dataLineInfo );
82
83             // listen to clip line for events
84             clip.addLineListener( this );
85
86             // open audio clip and get required system resources
87             clip.open( soundStream );
88
89          }  // end try
90
91          // line resource unavailable
92          catch ( LineUnavailableException noLineException ) {
93             noLineException.printStackTrace();
94             return false;
95          }
96
97          // I/O error during interpretation of audio data
98          catch ( IOException ioException ) {
99             ioException.printStackTrace();
100            return false;
101         }
102
103         // clip file loaded successfully
104         return true;
105
106      }  // end method loadClip
107
108      // start playback of audio clip
109      public void play()
110      {
111         clip.start();
112      }
113
114      // line event listener method to stop or replay at clip end
115      public void update( LineEvent lineEvent )
116      {
117         // if clip reaches end, close clip
118         if ( lineEvent.getType() == LineEvent.Type.STOP &&
119            !replay )
120            close();
121
```

Fig. 22.5 **`ClipPlayer`** plays an audio file (part 3 of 4).

```
122         // if replay set, replay forever
123         else
124
125            if ( lineEvent.getType() == LineEvent.Type.STOP &&
126               replay ) {
127
128               System.out.println( "replay" );
129
130               // replay clip forever
131               clip.loop( Clip.LOOP_CONTINUOUSLY );
132            }
133      }
134
135      // set replay of clip
136      public void setReplay( boolean value )
137      {
138         replay = value;
139      }
140
141      // stop and close clip, returning system resources
142      public void close()
143      {
144         if ( clip != null ) {
145            clip.stop();
146            clip.close();
147         }
148      }
149
150   }  // end class ClipPlayer
```

Fig. 22.5 **`ClipPlayer`** plays an audio file (part 4 of 4).

All **`Line`**s generate ***`LineEvent`***s, which can be handled by ***`LineListener`***s. **`LineEvent`**s occur when starting, stopping, playing and closing a **`Line`** object. Although a **`Line`** stops playback automatically when it reaches the end of an audio file, class **`ClipPlayer`** implements interface **`LineListener`** (line 10) and can close the **`Clip`** permanently or replay the **`Clip`** (discussed shortly). **`LineListener`**s are useful for tasks that must be synchronized with the **`LineEvent`** states of a line.

The **`Clip`** reads audio data from an ***`AudioInputStream`*** (a subclass of **`InputStream`**), which provides access to the stream's data content. This example loads clips of the audio data before attempting to play it, and therefore is able to determine the length of the clip in *frames*. Each frame represents data at a specific time interval in the audio file. To play sampled audio files using Java Sound, a program must obtain an **`AudioInputStream`** from an audio file, obtain a formatted **`Clip`** line, load the **`AudioInputStream`** into the **`Clip`** line and start the data flow in the **`Clip`** line.

To play back sampled audio, the audio stream must be obtained from an audio file. **`ClipPlayer`** method **`openFile`** (lines 31–54) obtains audio from **`soundFile`** (initialized in the **`ClipPlayer`** constructor at lines 25–28). Lines 35–36 call ***`AudioSystem`*** **`static`** method ***`getAudioInputStream`*** to obtain an **`AudioInputStream`** for **`soundFile`**. Class **`AudioSystem`** facilitates access to many of the resources needed to play and manipulate sound files. Method **`getAudioInputStream`** throws an ***`Unsup-`***

portedAudioFileException if the specified sound file is a non-audio file or if it contains a format that is not supported by Java Sound.

Next the program must provide a line through which audio data can be processed. Line 52 invokes method **loadClip** (lines 57–106) to open a **Clip** line and load the audio stream for playback. Line 81 invokes **AudioSystem** **static** method ***getLine*** to obtain a **Clip** line for audio playback. Method **getLine** requires a ***Line.Info*** object as an argument, to specify the attributes of the line that the **AudioSystem** should return. The line must be able to process audio clips of all supported sampled audio formats, so the ***DataLine.Info*** object must specify a **Clip** data line and a general encoding format. A buffer range should also be specified so the program can determine the best buffer size. The **DataLine.Info** constructor receives four arguments. The first two are the format (of type **AudioFormat.Encoding**) into which the program should convert the audio data and the ***AudioFormat*** of the audio source. The **AudioFormat** sets the format supported by the line, according to the audio format of the stream. Line 63 obtains the **AudioFormat** of the **AudioInputStream**, which contains format specifications that the underlying system uses to translate the data into sounds. Lines 68–69 call **AudioSystem** method ***getTargetFormats*** to obtain an array of the supported **AudioFormat**s. The third argument of the **DataLine.Info** constructor, which specifies the minimum buffer size, is set to the number of bytes in each frame of the audio stream. Line 70 invokes **AudioFormat** method ***getFrameSize*** to obtain the size of each frame in the audio stream. The maximum buffer size should be equivalent to two frames of the audio stream (line 71). Using the **DataLine.Info** object, line 74 checks if the underlying audio system supports the specified line. If it does, line 81 obtains the line from the audio system.

When an audio clip starts playing and when it finishes, the program needs to be alerted. Line 84 registers a **LineListener** for the **Clip**'s **LineEvent**s. If a **LineEvent** occurs, the program calls **LineListener** method **update** (lines 115–133) to process it. The four **LineEvent** types, as defined in class **LineEvent.Type**, are **OPEN**, **CLOSE**, **START** and **STOP**. When the event type is **LineEvent.Type.STOP** and variable **replay** is **false**, line 120 calls **ClipPlayer**'s **close** method (lines 142–148) to stop audio playback and close the **Clip**. All audio resources obtained previously by the **Clip** are released when audio playback stops. When the event type is **LineEvent.Type.STOP** and variable **replay** is **true**, line 131 calls **Clip** method ***loop*** with parameter ***Clip.LOOP_CONTINUOUSLY***, causing the **Clip** to loop until the user terminates the application. Invoking method **stop** of interface **Clip** stops data activity in the **Line**. Invoking method **start** resumes data activity.

Once the program finishes validating the **Clip**, line 87 calls **Clip** method **open** with the **AudioInputStream** **soundStream** as an argument. The **Clip** obtains the system resources required for audio playback. **AudioSystem** method **getLine** and **Clip** method **open** throw **LineUnavailableException**s if another application is using the requested audio resource. **Clip** method **open** also throws an **IOException** if the **Clip** cannot read the specified **AudioInputStream**. When the test program (Fig. 22.6) calls **ClipPlayer** method **play** (lines 109–112), the **Clip** method **start** begins audio playback.

Class **ClipPlayerTest** (Fig. 22.6) enables users to specify an audio file to play by clicking the **Open Audio Clip** button. When users click the button, method **actionPerformed** (lines 37–58) prompts an audio file name and location (line 39) and creates

a **ClipPlayer** for the specified audio file (line 44). Line 47 invokes **ClipPlayer** method **openFile**, which returns **true** if the **ClipPlayer** can open the audio file. If so, line 50 calls **ClipPlayer** method **play** to play the audio and line 53 calls **ClipPlayer** method **setReplay** to indicate that the audio should not loop continuously.

Performance Tip 22.4

Large audio files take a long time to load, depending on the speed of the computer. An alternative playback form is to buffer the audio by loading a portion of the data to begin playback and continuing to load the remainder as the audio plays. This is similar to the streaming capability provided by JMF.

```
1  // Fig. 22.6: ClipPlayerTest.java
2  // Test file for ClipPlayer
3
4  // Java core packages
5  import java.awt.*;
6  import java.awt.event.*;
7  import java.io.*;
8
9  // Java extension packages
10 import javax.swing.*;
11
12 public class ClipPlayerTest extends JFrame {
13
14    // object to play audio clips
15    private ClipPlayer clipPlayer;
16
17    // constructor for ClipPlayerTest
18    public ClipPlayerTest()
19    {
20       super( "Clip Player" );
21
22       // panel containing buttons
23       JPanel buttonPanel = new JPanel();
24       getContentPane().add( buttonPanel );
25
26       // open file button
27       JButton openFile = new JButton( "Open Audio Clip" );
28       buttonPanel.add( openFile, BorderLayout.CENTER );
29
30       // register ActionListener for openFile events
31       openFile.addActionListener(
32
33          // inner anonymous class to handle openFile ActionEvent
34          new ActionListener() {
35
36             // try to open and play an audio clip file
37             public void actionPerformed( ActionEvent event )
38             {
39                File mediaFile = getFile();
40
```

Fig. 22.6 **ClipPlayerTest** enables the user to specify the name and location of the audio to play with **ClipPlayer** (part 1 of 3).

```
41                if ( mediaFile != null ) {
42
43                   // instantiate new clip player with mediaFile
44                   clipPlayer = new ClipPlayer( mediaFile );
45
46                   // if clip player opened correctly
47                   if ( clipPlayer.openFile() == true ) {
48
49                      // play loaded clip
50                      clipPlayer.play();
51
52                      // no replay
53                      clipPlayer.setReplay( false );
54                   }
55
56                }  // end if mediaFile
57
58             }  // end actionPerformed
59
60          }  // end ActionListener
61
62       ); // end call to addActionListener
63
64    }  // end constructor
65
66    // get file from computer
67    public File getFile()
68    {
69       JFileChooser fileChooser = new JFileChooser();
70
71       fileChooser.setFileSelectionMode(
72          JFileChooser.FILES_ONLY );
73       int result = fileChooser.showOpenDialog( this );
74
75       if ( result == JFileChooser.CANCEL_OPTION )
76          return null;
77
78       else
79          return fileChooser.getSelectedFile();
80    }
81
82    // execute application
83    public static void main( String args[] )
84    {
85       ClipPlayerTest test = new ClipPlayerTest();
86
87       test.setSize( 150, 70 );
88       test.setLocation( 300, 300 );
89       test.setDefaultCloseOperation( EXIT_ON_CLOSE );
90       test.setVisible( true );
91    }
92
```

Fig. 22.6 **`ClipPlayerTest`** enables the user to specify the name and location of the audio to play with **`ClipPlayer`** (part 2 of 3).

```
93 }  // end class ClipPlayerTest
```

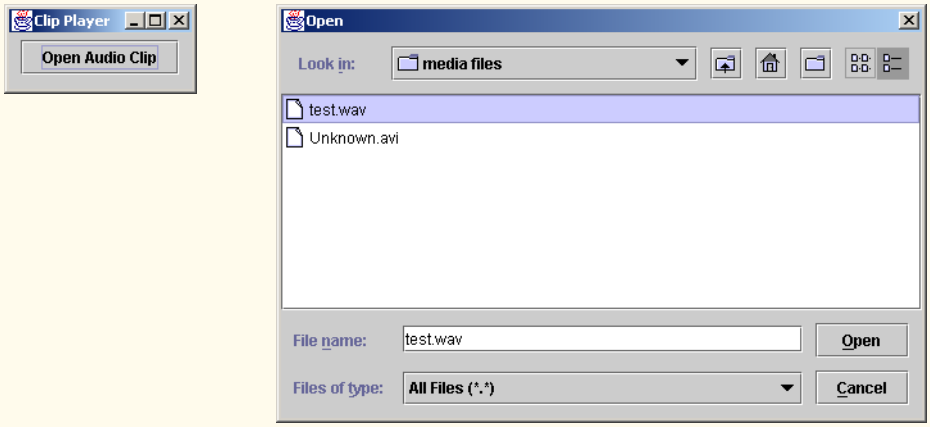

Fig. 22.6 **`ClipPlayerTest`** enables the user to specify the name and location of the audio to play with **`ClipPlayer`** (part 3 of 3).

22.7 Musical Instrument Digital Interface (MIDI)

The Musical Instrument Digital Interface (MIDI) is a standard format for electronic music. MIDI music can be created through a digital instrument, such as an electronic keyboard, or through software. The MIDI interface allows musicians to create synthesized digital music that reproduces the actual music. Then they can share their musical creations with music enthusiasts around the world. A MIDI *synthesizer* is a device that can produce MIDI sounds and music.

Programs can easily manipulate MIDI data. Like other types of audio, MIDI data has a well-defined format that MIDI players can interpret, play and use to create new MIDI data. The *Complete Detailed MIDI 1.0 specification* provides detailed information on MIDI files. Visit the official MIDI Web site at **`www.midi.org`** for information on MIDI and its specification. Java Sound's MIDI packages (**`javax.sound.midi`** and **`javax.sound.midi.spi`**) allow developers to access MIDI data.

Interpretation of MIDI data varies between synthesizers, so a file may sound quite different when played on synthesizers other than the one on which it was created. Synthesizers support varying types and numbers of instrumental sounds and different numbers of simultaneous sounds. Usually hardware-based synthesizers are capable of producing higher-quality synthesized music than software-based synthesizers.

Many Web sites and games use MIDI for music playback, as it enables developers to entertain users with lengthy, digitized music files that do not require a lot of memory. In comparison, sampled audio files can grow to be quite large. Package **`javax.sound.midi`** enables programs to manipulate, play and synthesize MIDI. Java Sound supports MIDI files with **`mid`** and **`rmf`** (Rich Music Format or RMF) extensions.

The example presented in Sections 22.7.1 through 22.7.4 covers MIDI synthesis, playback, recording and saving. Class **`MidiDemo`** (Fig. 22.10) is the main application class that utilizes classes **`MidiData`** (Fig. 22.7), **`MidiRecord`** (Fig. 22.8) and **`MidiSynthesizer`** (Fig. 22.9). Class **`MidiSynthesizer`** provides resources for generating sounds

and transmitting them to other MIDI devices, such as recorders. Class **`MidiData`** handles MIDI playback, track initialization and event information. Class **`MidiRecord`** provides MIDI recording capabilities. Class **`MidiDemo`** ties the other classes together with an interactive GUI that includes a simulated piano keyboard, play and record buttons, and a control panel for configuring MIDI options. Class **`MidiDemo`** also uses MIDI event-synchronization to play a MIDI file and highlight the appropriate piano keys, simulating someone playing the keyboard.

An integral part of this MIDI example is its GUI, which allows users to play musical notes on a simulated piano keyboard (see screen capture in Fig. 22.10). When the mouse hovers over a piano key, the program plays the corresponding note. In this section, we refer to this as *user synthesis*. The **Play MIDI** button in the GUI allows the user to select a MIDI file to play. The **Record** button records the notes played on the piano (user synthesis). Users can save the recorded MIDI to a file using the **Save MIDI** button and play back the recorded MIDI using the **PlayBack** button. Users can click the **Piano Player** button to open a MIDI file, then play that file back through a synthesizer. The program signifies synchronization of notes and piano keys by highlighting the key that corresponds to the note number. This playback and synchronization ability is called the "piano player." While the "piano player" is running, users can synthesize additional notes, and record both the old audio material and the new user-synthesized notes by clicking the **Record** button. The **`JComboBox`** in the upper-left corner of the GUI enables users to select an instrument for synthesis. Additional GUI components include a volume control for user-synthesized notes and a tempo control for controlling the speed of the "piano player."

Testing and Debugging Tip 22.1

Testing the MIDI file playback functions requires a sound card and an audio file in MIDI format.

22.7.1 MIDI Playback

This section discusses how to play MIDI files and how to access and interpret MIDI file contents. Class **`MidiData`** (Fig. 22.7) contains methods that load a MIDI file for playback. The class also provides the MIDI track information required by the "piano player" feature. A MIDI *sequencer* is used to play and manipulate the audio data. Often, MIDI data is referred to as a *sequence*, because the musical data in a MIDI file is composed of a sequence of events. The steps performed in MIDI playback are accessing a sequencer, loading a MIDI sequence or file into that sequencer and starting the sequencer.

```
1  // Fig. 22.7: MidiData.java
2  // Contains MIDI sequence information
3  // with accessor methods and MIDI playback methods
4
5  // Java core package
6  import java.io.*;
7
8  // Java extension package
9  import javax.sound.midi.*;
10
```

Fig. 22.7 **`MidiData`** loads MIDI files for playback (part 1 of 5).

```
11  public class MidiData {
12
13     // MIDI track data
14     private Track track;
15
16     // player for MIDI sequences
17     private Sequencer sequencer;
18
19     // MIDI sequence
20     private Sequence sequence;
21
22     // MIDI events containing time and MidiMessages
23     private MidiEvent currentEvent, nextEvent;
24
25     // MIDI message usually containing sounding messages
26     private ShortMessage noteMessage;
27
28     // short, meta, or sysex MIDI messages
29     private MidiMessage message;
30
31     // index of MIDI event in track, command in MIDI message
32     private int eventIndex = 0, command;
33
34     // method to play MIDI sequence via sequencer
35     public void play()
36     {
37        // initiate default sequencer
38        try {
39
40           // get sequencer from MidiSystem
41           sequencer = MidiSystem.getSequencer();
42
43           // open sequencer resources
44           sequencer.open();
45
46           // load MIDI into sequencer
47           sequencer.setSequence( sequence );
48
49           // play sequence
50           sequencer.start();
51        }
52
53        // MIDI resource availability error
54        catch ( MidiUnavailableException noMidiException ) {
55           noMidiException.printStackTrace();
56        }
57
58        // corrupted MIDI or invalid MIDI file encountered
59        catch ( InvalidMidiDataException badMidiException ) {
60           badMidiException.printStackTrace();
61
62        }
63
```

Fig. 22.7 **`MidiData`** loads MIDI files for playback (part 2 of 5).

```
64      }  // end method play
65
66      // method returning adjusted tempo/resolution of MIDI
67      public int getResolution()
68      {
69         return 500 / sequence.getResolution();
70      }
71
72      // obtain MIDI and prepare track in MIDI to be accessed
73      public boolean initialize( File file )
74      {
75         // get valid MIDI from file into sequence
76         try {
77            sequence = MidiSystem.getSequence( file );
78         }
79
80         // unreadable MIDI file or unsupported MIDI
81         catch ( InvalidMidiDataException badMIDI ) {
82            badMIDI.printStackTrace();
83            return false;
84         }
85
86         // I/O error generated during file reading
87         catch ( IOException ioException ) {
88            ioException.printStackTrace();
89            return false;
90         }
91
92         return true;
93
94      }  // end method initialize
95
96      // prepare longest track to be read and get first MIDI event
97      public boolean initializeTrack()
98      {
99         // get all tracks from sequence
100        Track tracks[] = sequence.getTracks();
101
102        if ( tracks.length == 0 ) {
103           System.err.println( "No tracks in MIDI sequence!" );
104
105           return false;
106        }
107
108        track = tracks[ 0 ];
109
110        // find longest track
111        for ( int i = 0; i < tracks.length; i++ )
112
113           if ( tracks[ i ].size() > track.size() )
114              track = tracks[ i ];
115
```

Fig. 22.7 **MidiData** loads MIDI files for playback (part 3 of 5).

```
116        // set current MIDI event to first event in track
117        currentEvent = track.get( eventIndex );
118
119        // get MIDI message from event
120        message = currentEvent.getMessage();
121
122        // track initialization successful
123        return true;
124
125     }  // end method initializeTrack
126
127     // move to next event in track
128     public void goNextEvent()
129     {
130        eventIndex++;
131        currentEvent = track.get( eventIndex );
132        message = currentEvent.getMessage();
133     }
134
135     // get time interval between events
136     public int getEventDelay()
137     {
138        // first event's time interval is its duration
139        if ( eventIndex == 0 )
140           return ( int ) currentEvent.getTick();
141
142        // time difference between current and next event
143        return ( int ) ( track.get( eventIndex + 1 ).getTick() -
144           currentEvent.getTick() );
145     }
146
147     // return if track has ended
148     public boolean isTrackEnd()
149     {
150        // if eventIndex is less than track's number of events
151        if ( eventIndex + 1 < track.size() )
152           return false;
153
154        return true;
155     }
156
157     // get current ShortMessage command from event
158     public int getEventCommand()
159     {
160        if ( message instanceof ShortMessage ) {
161
162           // obtain MidiMessage for accessing purposes
163           noteMessage = ( ShortMessage ) message;
164           return noteMessage.getCommand();
165        }
166
167        return -1;
168     }
```

Fig. 22.7 **`MidiData`** loads MIDI files for playback (part 4 of 5).

```
169
170     // get note number of current event
171     public int getNote()
172     {
173        if ( noteMessage != null )
174           return noteMessage.getData1();
175
176        return -1;
177     }
178
179     // get volume of current event
180     public int getVolume()
181     {
182        return noteMessage.getData2();
183     }
184
185  }  // end class MidiData
```

Fig. 22.7 **MidiData** loads MIDI files for playback (part 5 of 5).

To play a MIDI file with a sequence, a program must obtain the MIDI sequence and check for compatibility issues. **MidiData** method **initialize** (lines 73–94) obtains a ***Sequence*** of MIDI data from a file with ***MidiSystem*** method ***getSequence*** (line 77). A **Sequence** contains MIDI tracks, which, in turn, contain MIDI events. Each event encapsulates a MIDI message of instructions for the MIDI devices. Individual tracks of a MIDI sequence are analogous to tracks on a CD. However, while CD tracks are played in order, MIDI tracks are played in parallel. A MIDI track is a recorded sequence of data. MIDIs usually contain multiple tracks. Method **getSequence** can also obtain a MIDI sequence from a URL or an **InputStream**. Method **getSequence** throws an ***InvalidMidiDataException*** if the MIDI system detects an incompatible MIDI file.

Portability Tip 22.2

Because of incompatible file parsers in different operating systems, sequencers may not be able to play RMF files.

After obtaining a valid MIDI sequence, the program must obtain a sequencer and load the sequence into the sequencer. Method **play** (lines 35–64) in class **MidiData** calls **MidiSystem** method ***getSequencer*** (line 41) to obtain a ***Sequencer*** to play the **Sequence**. Interface **Sequencer**, which extends interface ***MidiDevice*** (the super-interface for all MIDI devices), provides the standard sequencer device to play MIDI data. If another program is using the same **Sequencer** object, method **getSequencer** throws a ***MidiUnavailableException***. Line 44 calls **Sequencer** method ***open*** to prepare to play a **Sequence**. **Sequencer** method ***setSequence*** (line 47) loads a MIDI **Sequence** into the **Sequencer** and throws an ***InvalidMidiException*** if the **Sequencer** detects an unrecognizable MIDI sequence. Line 50 begins playing the MIDI sequence by calling the **Sequencer**'s ***start*** method.

In addition to MIDI playback methods, class **MidiData** also provides methods that enable a program to access the events and messages of a MIDI sequence. As we shall see, class **MidiDemo** (Figure 22.10) uses class **MidiData** to access the data in a MIDI file for synchronizing the highlighting of piano keys. The MIDI events are stored in the MIDI's

tracks, which are instances of class **`Track`** (package **`javax.sound.midi`**). MIDI events in MIDI tracks are represented by class **`MidiEvent`** (package **`javax.sound.midi`**). Each MIDI event contains an instruction and the time at which it should occur. The individual events in a track contain messages of type **`MidiMessage`** that specify the MIDI instructions for a **`MidiDevice`**. There are three types of MIDI messages—**`ShortMessage`**, **`SysexMessage`** and **`MetaMessage`**. **`ShortMessage`**s are explicit musical instructions, such as the specific notes to play and pitch changes. The other two less-used messages are **`SysexMessage`**s, system-exclusive messages for MIDI devices, and **`MetaMessage`**s, which may indicate to a MIDI device that the MIDI has reached the end of a track. This section deals exclusively with **`ShortMessage`**s that play specific notes.

Next, the program must obtain the tracks and read their events. **`MidiData`** method **`initializeTrack`** (lines 97–125) invokes **`Sequence`**'s **`getTracks`** method (line 100) to obtain all of the tracks in the MIDI sequence. Lines 108–114 determine the longest track in the MIDI and set it as the one to play. Line 117 obtains the first MIDI event in the **`Track`** by invoking its **`get`** method with the index of the event in the track as the parameter. At this point **`eventIndex`** is set to **`0`** (line 32). Line 120 obtains the MIDI message from the MIDI event using method **`getMessage`** of class **`MidiEvent`**. To help a program step through each event in the tracks, the program can call **`MidiData`** method **`goNextEvent`** (lines 128–133) to load the next event and message. Method **`goNextEvent`** increments **`eventIndex`** in the loaded MIDI **`Track`** and finds the next event's **`MidiMessage`**.

In addition to reading the events, the program must also determine how long each event lasts and the spacing between events. Method **`getEventDelay`** (lines 136–145) returns the duration of a **`MidiEvent`** as the time difference between two events in the MIDI sequence (lines 143–144). The **`MidiEvent`**'s **`getTick`** method provides the specific time when the event takes place (also called a *time stamp*). Lines 139–140 return the first **`MidiEvent`**'s time stamp as the event's duration.

Class **`MidiData`** provides other methods to return the commands, the note numbers and the volume of note-related **`ShortMessage`**s. Method **`getEventCommand`** (lines 158–168) determines the command number representing the command instruction. Line 160 of method **`getEventCommand`** indicates whether the currently loaded **`MidiMessage`** is a **`ShortMessage`**. If so, line 163 assigns the **`ShortMessage`** to object **`noteMessage`** and line 164 returns the **`ShortMessage`**'s command status byte by invoking **`ShortMessage`**'s **`getCommand`** method. Method **`getEventCommand`** returns **`-1`** if the event does not contain a **`ShortMessage`**. **`MidiData`** method **`getNote`** (lines 171–177) invokes **`ShortMessage`** method **`getData1`** (line 174) to return the note number. Method **`getVolume`** (lines 180–183) invokes **`ShortMessage`** method **`getData2`** to return the volume. Class **`MidiData`** also provides an indication of the end of a track in method **`isTrackEnd`** (lines 148–155), which determines whether the event index has surpassed the number of events in the track (line 151).

22.7.2 MIDI Recording

A program can record MIDI using a sequencer. Class **`MidiRecord`** (Fig. 22.8) handles the recording functions of this MIDI demo using an object that implements interface **`Sequencer`** as a MIDI recorder. As long as the MIDI devices are set up correctly, interface **`Sequencer`** provides simple methods for recording. Class **`MidiRecord`** has a constructor (lines 29–32) that receives an object that implements interface **`Transmitter`** as an

argument. A **`Transmitter`** sends MIDI messages to a MIDI device that implements interface ***`Receiver`***. Think of **`Transmitter`**s and **`Receiver`**s as output and input ports respectively for MIDI devices.

```
1  // Fig. 22.8: MidiRecord.java
2  // Allows for recording and playback
3  // of synthesized MIDI
4
5  // Java core packages
6  import java.io.*;
7
8  // Java extension package
9  import javax.sound.midi.*;
10
11 public class MidiRecord {
12
13    // MIDI track
14    private Track track;
15
16    // MIDI sequencer to play and access music
17    private Sequencer sequencer;
18
19    // MIDI sequence
20    private Sequence sequence;
21
22    // receiver of MIDI events
23    private Receiver receiver;
24
25    // transmitter for transmitting MIDI messages
26    private Transmitter transmitter;
27
28    // constructor for MidiRecord
29    public MidiRecord( Transmitter transmit )
30    {
31       transmitter = transmit;
32    }
33
34    // initialize recording sequencer, set up recording sequence
35    public boolean initialize()
36    {
37       // create empty MIDI sequence and set up sequencer wiring
38       try {
39
40          // create tempo-based sequence of 10 pulses per beat
41          sequence = new Sequence( Sequence.PPQ, 10 );
42
43          // obtain sequencer and open it
44          sequencer = MidiSystem.getSequencer();
45          sequencer.open();
46
47          // get receiver of sequencer
48          receiver = sequencer.getReceiver();
```

Fig. 22.8 **`MidiRecord`** enables a program to record a MIDI sequence (part 1 of 3).

```
49
50             if ( receiver == null ) {
51                System.err.println(
52                   "Receiver unavailable for sequencer" );
53                return false;
54             }
55
56             // set receiver for transmitter to send MidiMessages
57             transmitter.setReceiver( receiver );
58
59             makeTrack();
60          }
61
62          // invalid timing division specification for new sequence
63          catch ( InvalidMidiDataException invalidMidiException ) {
64             invalidMidiException.printStackTrace();
65             return false;
66          }
67
68          // sequencer or receiver unavailable
69          catch ( MidiUnavailableException noMidiException ) {
70             noMidiException.printStackTrace();
71             return false;
72          }
73
74          // MIDI recorder initialization successful
75          return true;
76
77       }  // end method initialize
78
79       // make new empty track for sequence
80       public void makeTrack()
81       {
82          // if previous track exists, delete it first
83          if ( track != null )
84             sequence.deleteTrack( track );
85
86          // create track in sequence
87          track = sequence.createTrack();
88       }
89
90       // start playback of loaded sequence
91       public void play()
92       {
93          sequencer.start();
94       }
95
96       // start recording into sequence
97       public void startRecord()
98       {
99          // load sequence into recorder and start recording
100         try {
101            sequencer.setSequence( sequence );
```

Fig. 22.8 **MidiRecord** enables a program to record a MIDI sequence (part 2 of 3).

```
102
103            // set track to recording-enabled and default channel
104            sequencer.recordEnable( track, 0 );
105
106            sequencer.startRecording();
107         }
108
109         // sequence contains bad MIDI data
110         catch ( InvalidMidiDataException badMidiException ) {
111            badMidiException.printStackTrace();
112
113         }
114
115      }  // end method startRecord
116
117      // stop MIDI recording
118      public void stopRecord()
119      {
120         sequencer.stopRecording();
121      }
122
123      // save MIDI sequence to file
124      public void saveSequence( File file )
125      {
126         // get all MIDI supported file types
127         int[] fileTypes = MidiSystem.getMidiFileTypes( sequence );
128
129         if ( fileTypes.length == 0 ) {
130            System.err.println( "No supported MIDI file format!" );
131            return;
132         }
133
134         // write recorded sequence into MIDI file
135         try {
136            MidiSystem.write( sequence, fileTypes[ 0 ], file );
137         }
138
139         // error writing to file
140         catch ( IOException ioException ) {
141            ioException.printStackTrace();
142         }
143
144      }  // end method saveSequence
145
146   }  // end class MidiRecord
```

Fig. 22.8 **MidiRecord** enables a program to record a MIDI sequence (part 3 of 3).

The first step of recording MIDI data is similar to the playback mechanism in class **MidiData**. In addition to obtaining an empty sequence and a sequencer, a MIDI recording program needs to connect the transmitters and receivers. After successfully "wiring" the sequencer's receiver as the "IN PORT," the recorder loads the empty sequence into the sequencer to start recording to a new track in the sequence. The following discussion covers these steps.

Method **initialize** (lines 35–77) of class **MidiRecord** sets up the sequencer for recording. Line 41 of method **initialize** instantiates an empty sequence. **MidiRecord** will record data to the empty sequence once the transmitter is connected to the receiver. Line 48 obtains the recording sequencer's **receiver** and line 57 specifies that **transmitter** will send its messages to **receiver**.

MIDI messages must be placed in a track, so method **initialize** invokes method **makeTrack** (lines 80–88) to delete the previous existing **track** (line 84) and to create an empty **Track** (line 87). Method **makeTrack** can also be called from an external class to record a new sequence without instantiating new sequencers and a new sequence.

After setting up a sequencer and an empty sequence, calling **MidiRecord** method **startRecord** (lines 97–115) starts the recording process. Line 101 loads an empty sequence into the sequencer. **Sequencer** method ***recordEnable*** is called and passed the **track** object and a channel number as arguments (line 104), which enables recording on that **track**. Line 106 invokes **Sequencer**'s ***startRecording*** method to start the recording of MIDI events sent from the transmitter. **Sequencer**'s ***stopRecording*** method stops recording and is called in **MidiRecord**'s **stopRecord** method (lines 118–121).

Class **MidiRecord** can also supports save a recorded sequence to a MIDI file using its **saveSequence** method (lines 124–144). Although most MIDI sequences can support *MIDI type 0 files* (the most common type of MIDI file), the sequence should be checked for other supported file types. Line 127 obtains an array of MIDI file types supported by the system for writing a sequence to a file. The MIDI file types are represented by integer values of 0, 1 or 2. Using the first supported file type, the **MidiSystem** writes the sequence to a specified **File** (line 136) passed into method **saveSequence** as an argument. **MidiRecord**'s **play** method (lines 91–94) enables the program to play back the newly recorded sequence.

22.7.3 MIDI Synthesis

This **MidiDemo** program provides an interactive piano that generates notes according to the keys pressed by the user. Class **MidiSynthesizer** (Fig. 22.9) generates these notes directly, and sends them to another device. Specifically, it sends the notes to a sequencer's **receiver** through a **transmitter** to record the MIDI sequence. Class **MidiSynthesizer** uses an object that implements interface ***Synthesizer*** (a sub-interface of **MidiDevice**) to access the default synthesizer's sound generation, instruments, channel resources and sound banks. A ***SoundBank*** is the container for various ***Instrument***s, which instructs the computer on how to make the sound of a specific note. Different notes made by various instruments are played through a ***MidiChannel*** on different tracks simultaneously to produce symphonic melodies.

```
1  // Fig. 22.9: MidiSynthesizer.java
2  // Accessing synthesizer resources
3
4  // Java extension package
5  import javax.sound.midi.*;
6
```

Fig. 22.9 **MidiSynthesizer** can generate notes and send them to another MIDI device (part 1 of 4).

```
 7  public class MidiSynthesizer {
 8
 9     // main synthesizer accesses resources
10     private Synthesizer synthesizer;
11
12     // available instruments for synthesis use
13     private Instrument instruments[];
14
15     // channels through which notes sound
16     private MidiChannel channels[];
17     private MidiChannel channel;    // current channel
18
19     // transmitter for transmitting messages
20     private Transmitter transmitter;
21
22     // receiver end of messages
23     private Receiver receiver;
24
25     // short message containing sound commands, note, volume
26     private ShortMessage message;
27
28     // constructor for MidiSynthesizer
29     public MidiSynthesizer()
30     {
31        // open synthesizer, set receiver,
32        // obtain channels and instruments
33        try {
34           synthesizer = MidiSystem.getSynthesizer();
35
36           if ( synthesizer != null ) {
37
38              synthesizer.open();
39
40              // get transmitter of synthesizer
41              transmitter = synthesizer.getTransmitter();
42
43              if ( transmitter == null )
44                 System.err.println( "Transmitter unavailable" );
45
46              // get receiver of synthesizer
47              receiver = synthesizer.getReceiver();
48
49              if ( receiver == null )
50                 System.out.println( "Receiver unavailable" );
51
52              // get all available instruments in default
53              // soundbank or synthesizer
54              instruments = synthesizer.getAvailableInstruments();
55
56              // get all 16 channels from synthesizer
57              channels = synthesizer.getChannels();
58
```

Fig. 22.9 **`MidiSynthesizer`** can generate notes and send them to another MIDI device (part 2 of 4).

```
59              // assign first channel as default channel
60              channel = channels[ 0 ];
61           }
62
63           else
64              System.err.println( "No Synthesizer" );
65        }
66
67        // synthesizer, receiver or transmitter unavailable
68        catch ( MidiUnavailableException noMidiException ) {
69           noMidiException.printStackTrace();
70        }
71
72     }  // end constructor
73
74     // return available instruments
75     public Instrument[] getInstruments()
76     {
77        return instruments;
78     }
79
80     // return synthesizer's transmitter
81     public Transmitter getTransmitter()
82     {
83        return transmitter;
84     }
85
86     // sound note on through channel
87     public void midiNoteOn( int note, int volume )
88     {
89        channel.noteOn( note, volume );
90     }
91
92     // sound note off through channel
93     public void midiNoteOff( int note )
94     {
95        channel.noteOff( note );
96     }
97
98     // change to selected instrument
99     public void changeInstrument( int index )
100    {
101       Patch patch = instruments[ index ].getPatch();
102
103       channel.programChange( patch.getBank(),
104          patch.getProgram() );
105    }
106
107    // send custom MIDI messages through transmitter
108    public void sendMessage( int command, int note, int volume )
109    {
```

Fig. 22.9 **`MidiSynthesizer`** can generate notes and send them to another MIDI device (part 3 of 4).

```
110         // send a MIDI ShortMessage using this method's parameters
111         try {
112            message = new ShortMessage();
113
114            // set new message of command (NOTE_ON, NOTE_OFF),
115            // note number, volume
116            message.setMessage( command, note, volume );
117
118            // send message through receiver
119            receiver.send( message, -1 );
120         }
121
122         // invalid message values set
123         catch ( InvalidMidiDataException badMidiException ) {
124            badMidiException.printStackTrace();
125         }
126
127      }  // end method sendMessage
128
129   }  // end class MidiSynthesizer
```

Fig. 22.9 **`MidiSynthesizer`** can generate notes and send them to another MIDI device (part 4 of 4).

`MidiSynthesizer`'s constructor (lines 29–72) acquires the synthesizer and initializes related resources. Line 34 obtains a **`Synthesizer`** object from the **`MidiSystem`** and line 38 opens the **`Synthesizer`**. To enable sounds to be played and recorded at the same time, lines 41–47 obtain the **`Transmitter`** and **`Receiver`** of the **`Synthesizer`**. When a MIDI message is sent to the **`synthesizer`**'s **`receiver`**, the **`synthesizer`** executes the message's instruction, generating notes, and the **`transmitter`** sends that message to designated **`Receiver`**s of other **`MidiDevice`**s.

Common Programming Error 22.3

*A **`MidiUnavailableException`** occurs when a program attempts to acquire unavailable **`MidiDevice`** resources such as synthesizers and transmitters.*

MIDI messages are sent to the **`MidiSynthesizer`** from **`MidiDemo`** as a result of either pressing a piano key or a **`MidiEvent`** in the preloaded track of **`MidiData`**. A note can be generated by accessing the **`channels`** of the **`synthesizer`** directly. For simplicity, **`MidiSynthesizer`** uses only the first channel (out of a possible 16) to sound notes. Line 57 invokes **`Synthesizer`** method ***`getChannels`*** to obtain all 16 channels from **`synthesizer`**, and line 60 sets the default channel to the first channel. A **`MidiChannel`** sounds a note by calling its ***`noteOn`*** method with the note number (0–127) and a volume number as arguments. **`MidiChannel`**'s ***`noteOff`*** method turns off a note with just the note number as an argument. **`MidiSynthesizer`** accesses these **`MidiChannel`** methods through method **`midiNoteOn`** (lines 87–90) and method **`midiNoteOff`** (lines 93–96), respectively.

A synthesizer can use its default instruments to sound notes. Line 54 obtains the default instrument available through the synthesizer or through a default sound bank by invoking **`Synthesizer`** method ***`getAvailableInstruments`***. A sound bank usually has 128 instruments. The instrument in use can be changed by invoking **`MidiSynthesizer`**

method **changeInstrument** (lines 99–105). Lines 103–104 invoke **MidiChannel**'s ***programChange*** method to load the desired instrument program with the bank and program number obtained from **patch** (line 104) as the parameters. A ***Patch*** is the location of a loaded instrument.

Performance Tip 22.5

A program can import more instruments by loading a customized sound bank through ***Synthesizer*** *method* ***loadAllInstruments*** *with a* ***SoundBank*** *object.*

By sending **MidiMessage**s to a **Synthesizer**'s **Receiver**, a program can invoke the synthesizer to sound notes without using its channels. Sending **MidiMessage**s to a **MidiDevice**'s **Receiver** also allows the device's **Transmitter**s to send these messages to another **MidiDevice**'s **Receiver**.

In **MidiSynthesizer**'s **sendMessage** method (lines 108–127), lines 112–116 create a new **ShortMessage** from the parameters of method **sendMessage** and send the message to the synthesizer's receiver (line 119). Line 116 of method **sendMessage** invokes **ShortMessage** method ***setMessage*** to set the contents of the message's instructions using three **int** arguments: a command, the note to play and the volume of the note. Method **setMessage** throws an **InvalidMidiDataException** if the designated command and parameter values are invalid.

When creating a new **ShortMessage** using method **setMessage**, the meaning of the second and third arguments vary depending on the command. Command **ShortMessage.NOTE_ON** designates the second parameter to be the note number and third argument to be the velocity (i.e. volume) of the note. The **ShortMessage.PROGRAM_CHANGE** command designates the second argument as the instrument program to use and ignores the third argument.

Line 119 sends the created **ShortMessage** to the **synthesizer**'s **receiver** by calling **Receiver** method **send** with the **MidiMessage** and a time stamp as its arguments. **MidiSynthesizer** does not deal with the complexity of MIDI synthesis timing. The receiver sends a value of **-1** for the time stamp parameter to designate that the time stamp should be ignored. The sequence recorder in class **MidiRecord** takes care of timing issues when it receives the messages.

Up to this point, we have discussed the tools needed to create our MIDI piano. In brief synopsis, class **MidiDemo** (Fig. 22.10) uses class **MidiSynthesizer** to generate sounds and to access channels and instruments. **MidiDemo** uses **MidiData** to playback MIDI files and access MIDI track information. **MidiRecord** provides the recording function for **MidiDemo**, which receives messages from **MidiSynthesizer**.

22.7.4 Class MidiDemo

We now present class **MidiDemo** (Fig. 22.10), which provides the GUI for our piano as well as other GUI components to control the capabilities of this example.

Using a **for** loop, utility method **makeKeys** (lines 86–155) in class **MidiDemo** creates 64 buttons that represent 64 different piano keys. Whenever the mouse hovers over a key, the program sounds the designated note. Method **makeKeys** arranges the keys at the bottom of the frame using each button's ***setBounds*** method (line 106) to designate the location and size of the buttons. The program arranges the buttons horizontally according to their index in array **noteButton**.

```
1  // Fig. 22.10: MidiDemo.java
2  // Simulates a musical keyboard with various
3  // instruments to play, also featuring recording, MIDI file
4  // playback and simulating MIDI playback with the keyboard
5
6  // Java core packages
7  import java.awt.*;
8  import java.awt.event.*;
9  import java.io.*;
10
11 // Java extension packages
12 import javax.swing.*;
13 import javax.swing.event.*;
14 import javax.sound.midi.*;
15
16 public class MidiDemo extends JFrame {
17
18    // recording MIDI data
19    private MidiRecord midiRecord;
20
21    // synthesize MIDI functioning
22    private MidiSynthesizer midiSynthesizer;
23
24    // MIDI data in MIDI file
25    private MidiData midiData;
26
27    // timer for simulating MIDI on piano
28    private Timer pianoTimer;
29
30    // piano keys
31    private JButton noteButton[];
32
33    // volume, tempo sliders
34    private JSlider volumeSlider, resolutionSlider;
35
36    // containers and panels holding GUI
37    private Container container;
38    private JPanel controlPanel, buttonPanel;
39
40    // instrument selector and buttons GUI
41    private JComboBox instrumentBox;
42    private JButton playButton, recordButton,
43       saveButton, pianoPlayerButton, listenButton;
44
45    // tempo, last piano key invoked, volume of MIDI
46    private int resolution, lastKeyOn = -1, midiVolume = 40;
47
48    // boolean value indicating if program is in recording mode
49    private boolean recording = false;
50
51    // first note number of first piano key, max number of keys
52    private static int FIRST_NOTE = 32, MAX_KEYS = 64;
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 1 of 14).

```
53
54     // constructor for MidiDemo
55     public MidiDemo()
56     {
57        super( "MIDI Demo" );
58
59        container = getContentPane();
60        container.setLayout( new BorderLayout() );
61
62        // synthesizer must be instantiated to enable synthesis
63        midiSynthesizer = new MidiSynthesizer();
64
65        // make piano keys
66        makeKeys();
67
68        // add control panel to frame
69        controlPanel = new JPanel( new BorderLayout() );
70        container.add( controlPanel, BorderLayout.NORTH );
71
72        makeConfigureControls();
73
74        // add button panel to frame
75        buttonPanel = new JPanel( new GridLayout( 5, 1 ) );
76        controlPanel.add( buttonPanel, BorderLayout.EAST );
77
78        // make GUI
79        makePlaySaveButtons();
80        makeRecordButton();
81        makePianoPlayerButton();
82
83     }  // end constructor
84
85     // utility method making piano keys
86     private void makeKeys()
87     {
88        // panel containing keys
89        JPanel keyPanel = new JPanel( null );
90        container.add( keyPanel, BorderLayout.CENTER );
91
92        // piano keys
93        noteButton = new JButton[ MAX_KEYS ];
94
95        // add MAX_KEYS buttons and what note they sound
96        for ( int i = 0; i < MAX_KEYS; i++ ) {
97
98           final int note = i;
99
100          noteButton[ i ] = new JButton();
101
102          // setting white keys
103          noteButton[ i ].setBackground( Color.white );
104
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 2 of 14).

```
105          // set correct spacing for buttons
106          noteButton[ i ].setBounds( ( i * 11 ), 1, 11, 40 );
107          keyPanel.add( noteButton[ i ] );
108
109          // register a mouse listener for mouse events
110          noteButton[ i ].addMouseListener(
111
112             // anonymous inner class to handle mouse events
113             new MouseAdapter() {
114
115                // invoke key note when mouse touches key
116                public void mouseEntered( MouseEvent mouseEvent )
117                {
118                   // if recording, send message to receiver
119                   if ( recording )
120                      midiSynthesizer.sendMessage(
121                         ShortMessage.NOTE_ON,
122                         note + FIRST_NOTE, midiVolume );
123
124                   // else just sound the note
125                   else
126                      midiSynthesizer.midiNoteOn(
127                         note + FIRST_NOTE, midiVolume );
128
129                   // turn key color to blue
130                   noteButton[ note ].setBackground(
131                      Color.blue );
132                }
133
134                // turn key note off when mouse leaves key
135                public void mouseExited( MouseEvent mouseEvent )
136                {
137                   if ( recording )
138                      midiSynthesizer.sendMessage(
139                         ShortMessage.NOTE_OFF,
140                         note + FIRST_NOTE, midiVolume );
141                   else
142                      midiSynthesizer.midiNoteOff(
143                         note + FIRST_NOTE );
144
145                   noteButton[ note ].setBackground(
146                      Color.white );
147                }
148
149             }  // end MouseAdapter
150
151          ); // end call to addMouseListener
152
153       }  // end for loop
154
155    }  // end method makeKeys
156
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 3 of 14).

```
157    // set up configuration controls
158    private void makeConfigureControls()
159    {
160       JPanel configurePanel =
161          new JPanel( new GridLayout( 5, 1 ) );
162
163       controlPanel.add( configurePanel, BorderLayout.WEST );
164
165       instrumentBox = new JComboBox(
166          midiSynthesizer.getInstruments() );
167
168       configurePanel.add( instrumentBox );
169
170       // register an ActionListener for instrumentBox events
171       instrumentBox.addActionListener(
172
173          // anonymous inner class to handle instrument selector
174          new ActionListener() {
175
176             // change current instrument program
177             public void actionPerformed( ActionEvent event )
178             {
179                // change instrument in synthesizer
180                midiSynthesizer.changeInstrument(
181                   instrumentBox.getSelectedIndex() );
182             }
183
184          }  // end ActionListener
185
186       ); // end call to method addActionListener
187
188       JLabel volumeLabel = new JLabel( "volume" );
189       configurePanel.add( volumeLabel );
190
191       volumeSlider = new JSlider(
192          SwingConstants.HORIZONTAL, 5, 80, 30 );
193
194       // register a ChangeListener for slider change events
195       volumeSlider.addChangeListener(
196
197          // anonymous inner class to handle volume slider events
198          new ChangeListener() {
199
200             // change volume
201             public void stateChanged( ChangeEvent changeEvent )
202             {
203                midiVolume = volumeSlider.getValue();
204             }
205
206          }  // end class ChangeListener
207
208       ); // end call to method addChangeListener
```

Fig. 22.10 **`MidiDemo`** provides the GUI than enables users to interact with the application (part 4 of 14).

```
209
210         configurePanel.add( volumeSlider );
211
212         JLabel tempLabel = new JLabel( "tempo" );
213         configurePanel.add( tempLabel );
214
215         resolutionSlider = new JSlider(
216            SwingConstants.HORIZONTAL, 1, 10, 1 );
217
218         // register a ChangeListener slider for change events
219         resolutionSlider.addChangeListener(
220
221            // anonymous inner class to handle tempo slider events
222            new ChangeListener() {
223
224               // change resolution if value changed
225               public void stateChanged( ChangeEvent changeEvent )
226               {
227                  resolution = resolutionSlider.getValue();
228               }
229
230            }  // end ChangeListener
231
232         ); // end call to method addChangeListener
233
234         resolutionSlider.setEnabled( false );
235         configurePanel.add( resolutionSlider );
236
237      }  // end method makeConfigureControls
238
239      // set up play and save buttons
240      private void makePlaySaveButtons()
241      {
242         playButton = new JButton( "Playback" );
243
244         // register an ActionListener for playButton events
245         playButton.addActionListener(
246
247            // anonymous inner class to handle playButton event
248            new ActionListener() {
249
250               // playback last recorded MIDI
251               public void actionPerformed( ActionEvent event )
252               {
253                  if ( midiRecord != null )
254                     midiRecord.play();
255               }
256
257            }  // end ActionListener
258
259         ); // end call to method addActionListener
260
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 5 of 14).

```
261         buttonPanel.add( playButton );
262         playButton.setEnabled( false );
263
264         listenButton = new JButton( "Play MIDI" );
265
266         // register an ActionListener for listenButton events
267         listenButton.addActionListener(
268
269            // anonymous inner class to handle listenButton events
270            new ActionListener() {
271
272               // playback MIDI file
273               public void actionPerformed( ActionEvent event )
274               {
275                  File midiFile = getFile();
276
277                  if ( midiFile == null )
278                     return;
279
280                  midiData = new MidiData();
281
282                  // prepare MIDI track
283                  if ( midiData.initialize( midiFile ) == false )
284                     return;
285
286                  // play MIDI data
287                  midiData.play();
288               }
289
290            }  // end ActionListener
291
292         ); // end call to method addActionListener
293
294         buttonPanel.add( listenButton );
295
296         saveButton = new JButton( "Save MIDI" );
297
298         // register an ActionListener for saveButton events
299         saveButton.addActionListener(
300
301            // anonymous inner class to handle saveButton events
302            new ActionListener() {
303
304               // get save file and save recorded MIDI
305               public void actionPerformed( ActionEvent event )
306               {
307                   File saveFile = getSaveFile();
308
309                   if ( saveFile != null )
310                      midiRecord.saveSequence( saveFile );
311               }
312
```

Fig. 22.10 **`MidiDemo`** provides the GUI than enables users to interact with the application (part 6 of 14).

```
313          }  // end ActionListener
314
315       ); // end call to method addActionListener
316
317       buttonPanel.add( saveButton );
318       saveButton.setEnabled( false );
319
320    }  // end method makePlaySaveButtons
321
322    // make recording button
323    private void makeRecordButton()
324    {
325       recordButton = new JButton( "Record" );
326
327       // register an ActionListener for recordButton events
328       recordButton.addActionListener(
329
330          // anonymous inner class to handle recordButton events
331          new ActionListener() {
332
333             // start or stop recording
334             public void actionPerformed( ActionEvent event )
335             {
336                // record MIDI when button is "record" button
337                if ( recordButton.getText().equals("Record") ) {
338
339                   if ( midiRecord == null ) {
340
341                      // create new instance of recorder
342                      // by passing in synthesizer transmitter
343                      midiRecord = new MidiRecord(
344                         midiSynthesizer.getTransmitter() );
345
346                      if ( midiRecord.initialize() == false )
347                         return;
348                   }
349
350                   else
351                      midiRecord.makeTrack();
352
353                   midiRecord.startRecord();
354
355                   // disable playback during recording
356                   playButton.setEnabled( false );
357
358                   // change recording button to stop
359                   recordButton.setText( "Stop" );
360                   recording = true;
361
362                }  // end if
363
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 7 of 14).

```
364                // stop recording when button is "stop" button
365                else {
366                   midiRecord.stopRecord();
367
368                   recordButton.setText( "Record" );
369                   recording = false;
370
371                   playButton.setEnabled( true );
372                   saveButton.setEnabled( true );
373                }
374
375             }  // end method actionPerformed
376
377          }  // end ActionListener
378
379       ); // end call to method addActionListener
380
381       buttonPanel.add( recordButton );
382
383    } // end method makeRecordButton
384
385    // create Piano Player button and functionality
386    private void makePianoPlayerButton()
387    {
388       pianoPlayerButton = new JButton( "Piano Player" );
389
390       // register an ActionListener for pianoPlayerButton events
391       pianoPlayerButton.addActionListener(
392
393          // anonymous inner class to handle pianoPlayerButton
394          new ActionListener() {
395
396             // initialize MIDI data and piano player timer
397             public void actionPerformed( ActionEvent event )
398             {
399                File midiFile = getFile();
400
401                if ( midiFile == null )
402                   return;
403
404                midiData = new MidiData();
405
406                // prepare MIDI track
407                if ( midiData.initialize( midiFile ) == false )
408                   return;
409
410                if ( midiData.initializeTrack() == false )
411                   return;
412
413                // set initial resolution from MIDI
414                resolution = midiData.getResolution();
415
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 8 of 14).

```
416                // new instance of timer for handling
417                // piano sounds and key pressing with tempo
418                pianoTimer = new Timer(
419                   midiData.getEventDelay() * resolution,
420                   new TimerHandler() );
421
422                listenButton.setEnabled( false );
423                pianoPlayerButton.setEnabled( false );
424                resolutionSlider.setEnabled( true );
425
426                pianoTimer.start();
427
428             }  // method end actionPerformed
429
430          }  // end ActionListener
431
432       ); // end call to method addActionListener
433
434       buttonPanel.add( pianoPlayerButton );
435
436    }  // end method makePianoPlayerButton
437
438    // inner class handles MIDI timed events
439    private class TimerHandler implements ActionListener {
440
441       // simulate key note of event if present, jump to next
442       // event in track and set next delay interval of timer
443       // method invoked when timer reaches next event time
444       public void actionPerformed( ActionEvent actionEvent )
445       {
446          // if valid last key on, set it white
447          if ( lastKeyOn != -1 )
448             noteButton[ lastKeyOn ].setBackground(
449                Color.white );
450
451          noteAction();
452          midiData.goNextEvent();
453
454          // stop piano player when end of MIDI track
455          if ( midiData.isTrackEnd() == true ) {
456
457             if ( lastKeyOn != -1 )
458                noteButton[ lastKeyOn ].setBackground(
459                   Color.white );
460
461             pianoTimer.stop();
462
463             listenButton.setEnabled( true );
464             pianoPlayerButton.setEnabled( true );
465             resolutionSlider.setEnabled( false );
466
467             return;
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 9 of 14).

```
468
469            }  // end if isTrackEnd
470
471            // set interval before next sounding event
472            pianoTimer.setDelay(
473               midiData.getEventDelay() * resolution );
474
475         }  // end actionPerformed method
476
477      }  // end inner class TimerHandler
478
479      // determine which note to sound
480      // according to MIDI messages
481      private void noteAction()
482      {
483         // during Note On message, sound note and press key
484         if ( midiData.getEventCommand() ==
485            ShortMessage.NOTE_ON ) {
486
487            // make sure valid note is in range of keys
488            if ( ( midiData.getNote() >= FIRST_NOTE ) &&
489               ( midiData.getNote() < FIRST_NOTE + MAX_KEYS ) ) {
490
491               lastKeyOn = midiData.getNote() - FIRST_NOTE;
492
493               // set key color to red
494               noteButton[ lastKeyOn ].setBackground( Color.red );
495
496               // send and sound note through synthesizer
497               midiSynthesizer.sendMessage( 144,
498                  midiData.getNote(), midiData.getVolume() );
499
500            }  // end if
501
502            // else no last key pressed
503            else
504               lastKeyOn = -1;
505
506         }  // end if
507
508         // receiving Note Off message will sound off note
509         // and change key color back to white
510         else
511
512            // if message command is note off
513            if ( midiData.getEventCommand() ==
514               ShortMessage.NOTE_OFF ) {
515
516               if ( ( midiData.getNote() >= FIRST_NOTE ) &&
517                  ( midiData.getNote() < FIRST_NOTE + MAX_KEYS ) ) {
518
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 10 of 14).

```
519                // set appropriate key to white
520                noteButton[ midiData.getNote() -
521                   FIRST_NOTE ].setBackground( Color.white );
522
523                // send note off message to receiver
524                midiSynthesizer.sendMessage( 128,
525                   midiData.getNote(), midiData.getVolume() );
526             }
527
528          }  // end if
529
530       }     // end method noteAction
531
532       // get save file from computer
533       public File getSaveFile()
534       {
535          JFileChooser fileChooser = new JFileChooser();
536
537          fileChooser.setFileSelectionMode(
538             JFileChooser.FILES_ONLY );
539          int result = fileChooser.showSaveDialog( this );
540
541          if ( result == JFileChooser.CANCEL_OPTION )
542             return null;
543
544          else
545             return fileChooser.getSelectedFile();
546       }
547
548       // get file from computer
549       public File getFile()
550       {
551          JFileChooser fileChooser = new JFileChooser();
552
553          fileChooser.setFileSelectionMode(
554             JFileChooser.FILES_ONLY );
555          int result = fileChooser.showOpenDialog( this );
556
557          if ( result == JFileChooser.CANCEL_OPTION )
558             return null;
559
560          else
561             return fileChooser.getSelectedFile();
562       }
563
564       // execute application
565       public static void main( String args[] )
566       {
567          MidiDemo midiTest = new MidiDemo();
568
569          midiTest.setSize( 711, 225 );
570          midiTest.setDefaultCloseOperation ( EXIT_ON_CLOSE );
```

Fig. 22.10 **MidiDemo** provides the GUI than enables users to interact with the application (part 11 of 14).

```
571         midiTest.setVisible( true );
572      }
573
574   }  // end class MidiDemo
```

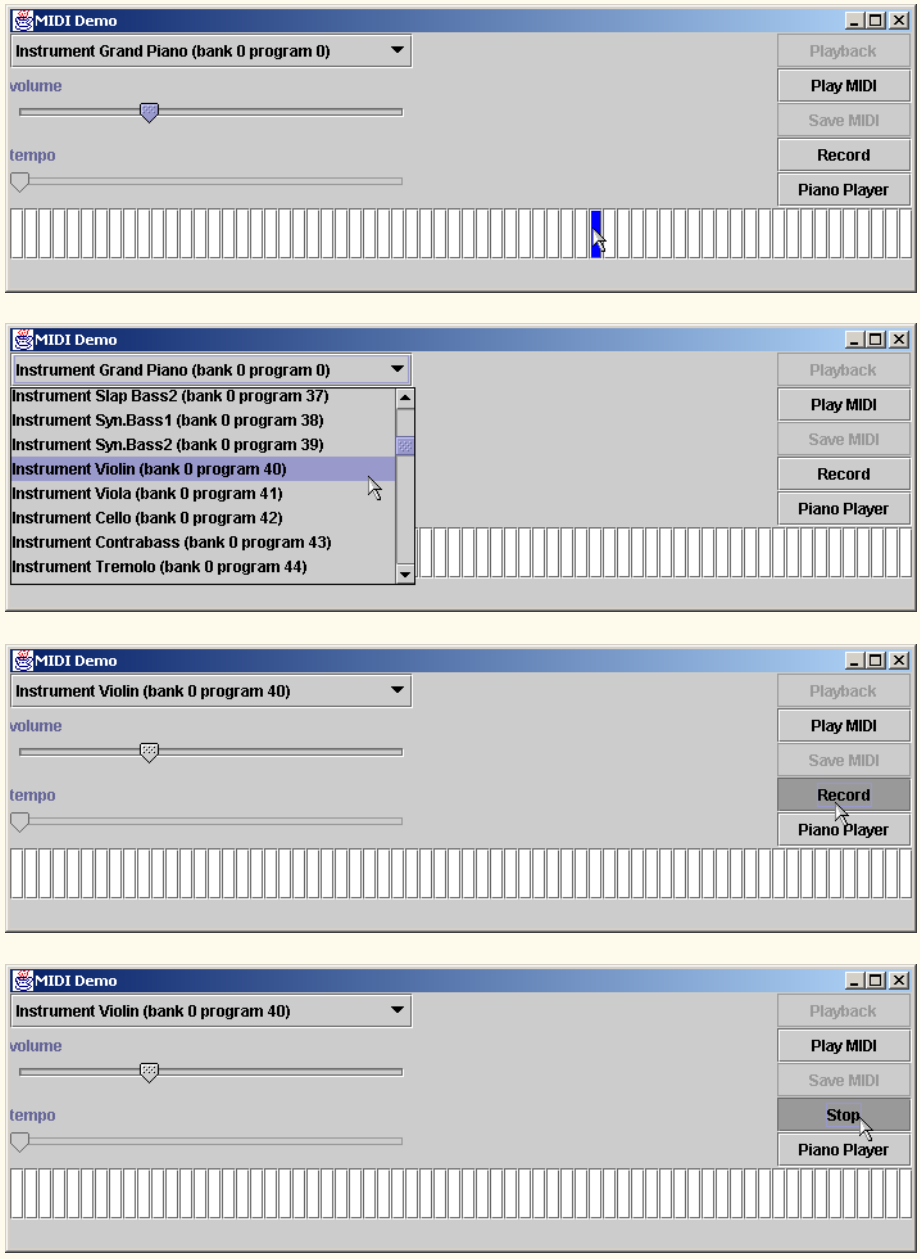

Fig. 22.10 **`MidiDemo`** provides the GUI than enables users to interact with the application (part 12 of 14).

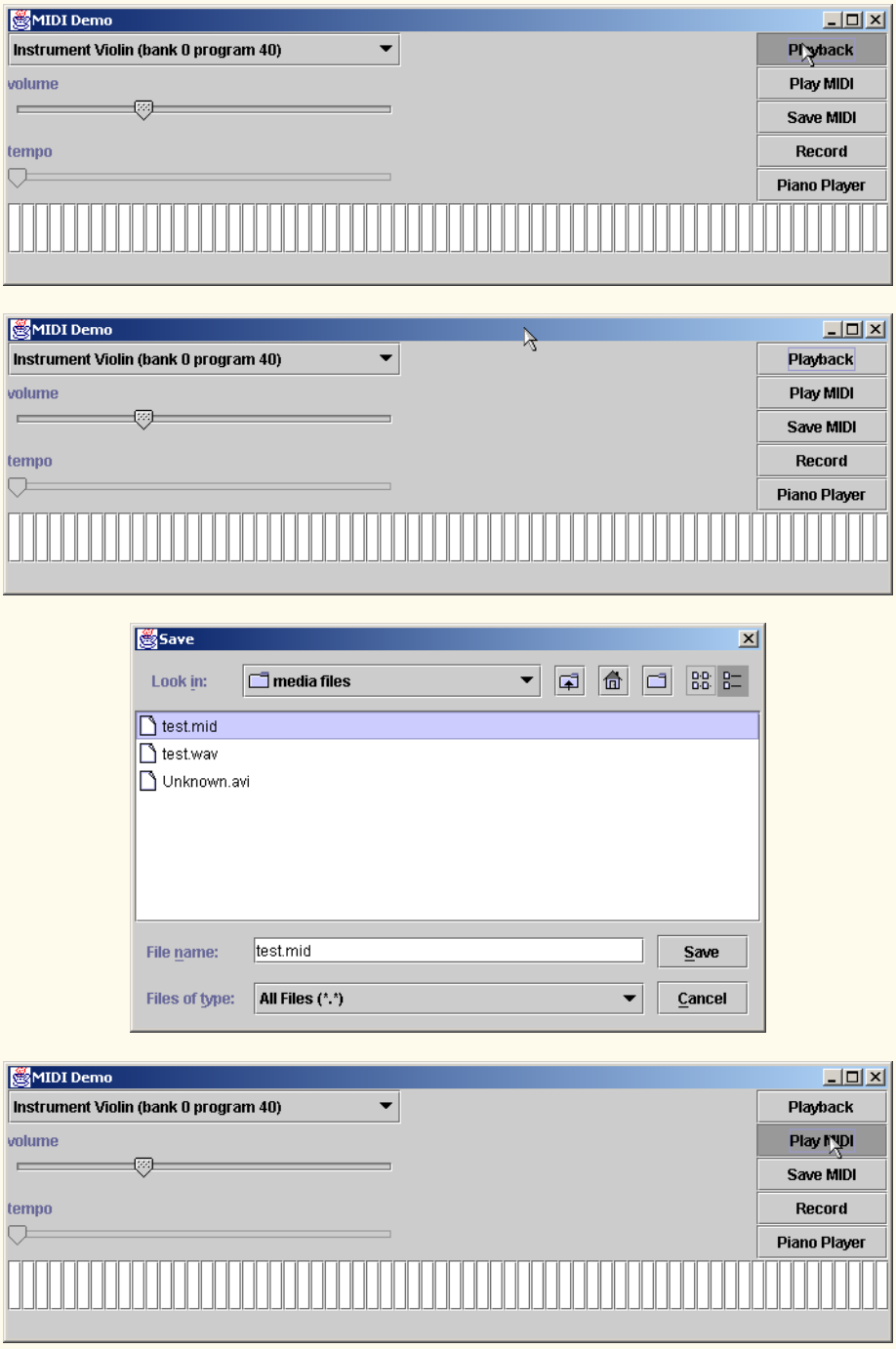

Fig. 22.10 **`MidiDemo`** provides the GUI than enables users to interact with the application (part 13 of 14).

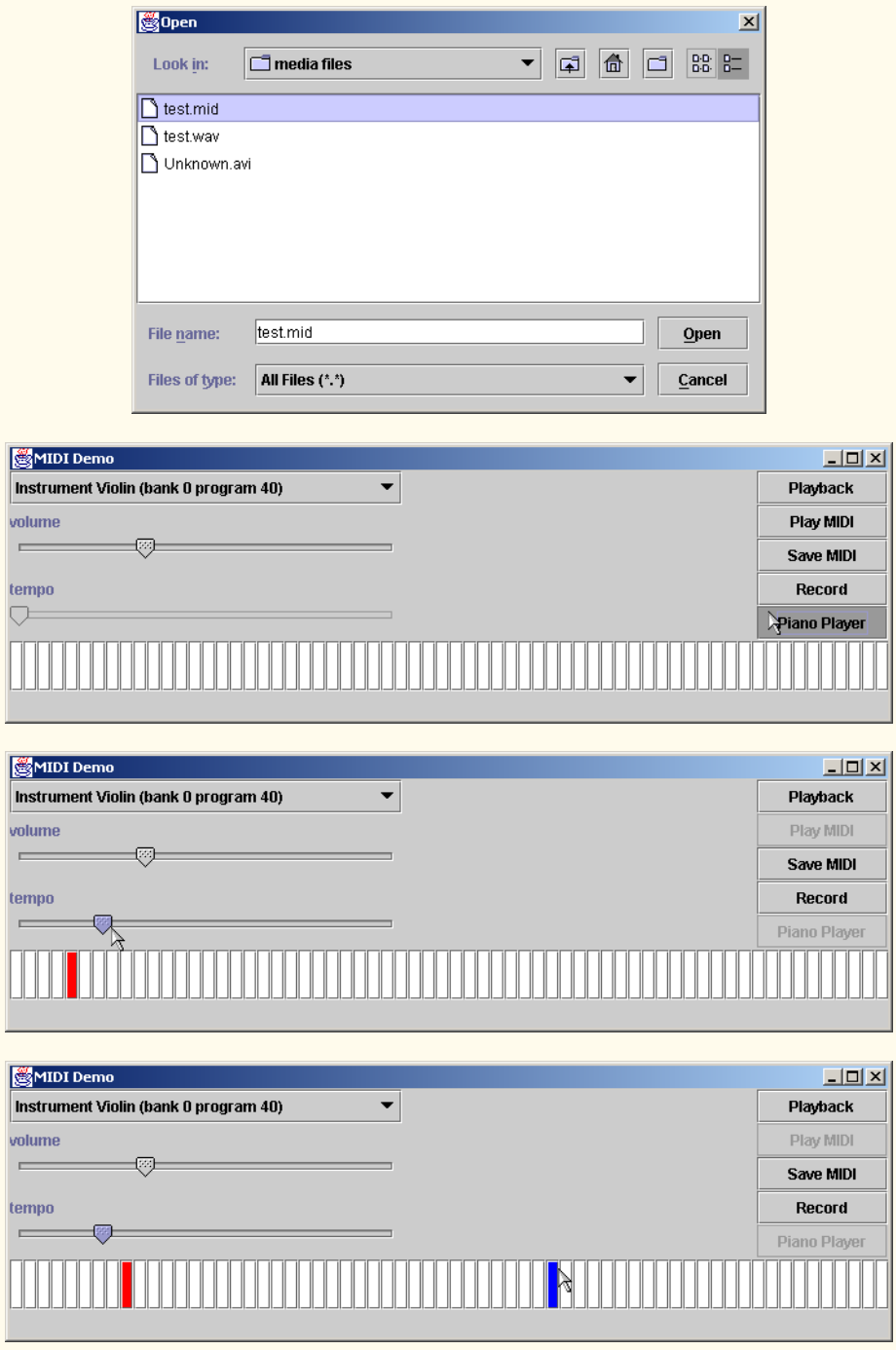

Fig. 22.10 **`MidiDemo`** provides the GUI than enables users to interact with the application (part 14 of 14).

Look-and-Feel Observation 22.3

To arrange GUI components at specific locations without the help of Layout Managers, set the layout of the panel containing the components to **`null`**. *By default, a* **`JPanel`** *sets a* **`FlowLayout`** **`LayoutManager`** *when the panel is instantiated with no arguments.*

Lines 110–151 register **`MouseListener`**s for each piano-key button. The program calls method **`mouseEntered`** (lines 116–132) when the mouse hovers over that button. If the program is not in recording mode, method **`mouseEntered`** directly accesses the channels in class **`MidiSynthesizer`** to sound the note (lines 125–127). Otherwise, method **`mouseEntered`** invokes **`MidiSynthesizer`**'s **`sendMessage`** method to send a note message to the synthesizer and to the recording device (lines 119–122). Lines 130–131 set the button's background color to blue to indicate that the note is being played. When the mouse is no longer hovering over the button, the program calls method **`mouseExited`** (lines 135–147) to turn off the note and change the button's background to its original color.

Out of the possible 128 notes, only the middle 64 notes are accessible via the piano in the example. The range of notes can be changed by modifying the constants in line 52. Constant **`FIRST_NOTE`** is the value of the first key and the sum of **`FIRST_NOTE`** and **`MAX_KEYS`** is the value of the last key. Constant **`MAX_KEYS`** specifies the number of piano keys to create.

Class **`MidiDemo`** invokes method **`makeConfigureControls`** (lines 158–237) to setup the program's MIDI controls, which consist of an instrument selector **`JComboBox`**, a user-synthesis volume changer **`JSlider`** and a "piano player" tempo changer **`JSlider`**. When users select an instrument, the program calls **`instrumentBox`** method **`actionPerformed`** (lines 177–182) to change to the selected instrument program by invoking **`MidiSynthesizer`** method **`changeInstrument`** with the selected instrument index as the parameter.

When users drag the volume slider, the program calls **`volumeSlider`** method **`stateChanged`** (lines 201-204) to change the volume. Note that changing the volume affects only the volume of user-synthesized MIDI notes. When users drag the tempo slider, the program calls **`resolutionSlider`**'s **`stateChanged`** method (lines 225-228) to set the tempo.

Invoking method **`makePlaySaveButtons`** (lines 240–320) sets up the **Play MIDI**, **Playback** and **Save** buttons. Clicking **Play MIDI** invokes the **`actionPerformed`** method of the **`listenButton`** (lines 273–288) to playback an opened MIDI file in its entirety using class **`MidiData`**. Line 275 obtains a file from a file-chooser dialog using **`MidiDemo`** method **`getFile`** (lines 549–562). Lines 280–284 initialize and play the MIDI file using the instantiated **`midiData`** object. When the user clicks **Playback**, line 254 plays the recorded MIDI. This button is enabled only if some recording took place. Clicking the **Save** button allows the user to save the recorded sequence to a file (lines 307–310).

Method **`makeRecordButton`** (lines 323–383) creates the **Record** button and a listener for it. Clicking the button when it is set to recording mode (line 337) creates a new recorder using class **`MidiRecord`** (lines 339–348). If a recorder has already been created, line 351 invokes **`MidiRecord`**'s **`makeTrack`** method to make a new track for object **`midiRecord`**. When recording starts (line 353), lines 356–360 turn the recording button into a stop button and disable the **`playButton`** temporarily. When users stop the recording by clicking the recording button again, the GUI returns to its state prior to recording and the user can playback and save the MIDI sequence (lines 365–373).

"Piano Player"

The "piano player" feature of this example synchronizes the playing of a note with the highlighting of the corresponding key. The program first obtains a MIDI track from a user-specified MIDI file using class **`MidiData`**. A **`Timer`** synchronizes the MIDI events in the MIDI sequence. When the **`Timer`** reaches a MIDI event's time stamp, it resets its *delay* to the time stamp of the next event to synchronize. The delay of a timer is the period of time that it waits before it causes an event.

The "piano player driver" responsible for synchronization is located in main class **`MidiDemo`**. Method **`makePianoPlayerButton`** (lines 386–436) loads the MIDI file and initializes the Timer that handles the timing of musical notes. As with the **`listenButton`**, method **`actionPerformed`** (lines 397–428) of **`makePlayerPianoButton`** uses class **`MidiData`** to load MIDI data. Lines 399–408 open a file from a file dialog box and load the MIDI data from the file. Line 410 invokes **`MidiData`**'s **`initializeTrack`** method to obtain the longest track from the loaded MIDI and to obtain the first MIDI event message from the track.

Line 414 invokes **`MidiData`**'s **`getResolution`** method (lines 67–70 in Fig. 22.7) to obtain the default tempo of the "piano player". Lines 418–420 instantiate a new **`Timer`** object that drives the playing of notes at the time of each MIDI event. Line 419 sets the delay of the timer to be the duration of the first **`MidiEvent`** in the track by invoking **`MidiData`**'s **`getEventDelay`** method. To allow user-specified tempo changes to the "piano player," line 424 enables the tempo slider and line 419 sets the delay of the timer to be multiplied by the value of **`resolution`**. The **`resolution`** variable, which specifies the tempo of "piano player," is multiplied by the event interval time to obtain a new interval time used by **`pianoTimer`**. **`PianoTimer`**'s delay is set only for the first event's duration to start the timer. Later, inner class **`TimerHandler`** (lines 439–477) method **`actionPerformed`** (lines 444–475) resets the timer's delay to the next **`MidiEvent`**'s duration (lines 472–473). Line 426 starts the **`pianoTimer`**.

At the time of the next MIDI event, class **`TimerHandler`**'s **`actionPerformed`** method synthesizes a note from the track and "presses" a key on the piano. Using **`pianoTimer`** and its event handler, the program iterates through the track, simulating note events when it encounters appropriate **`MidiEvent`**s. Inner class **`TimerHandler`** drives the synchronization by iterating through all the **`MidiEvent`**s on a given track and calling method **`actionPerformed`** to play the piano. Line 451 of method **`actionPerformed`** invokes utility method **`noteAction`** (lines 481–530) to sound the note and to change the color of the specific piano key, given that the event contains a note message and that the note is within the range designator for the piano keys in this example.

Lines 484–485 of method **`noteAction`** determine whether the current **`MidiEvent`** contains a note command by invoking method **`getEventCommand`** of class **`MidiData`**. Lines 488–489 invoke **`MidiData`** method **`getNote`** to determine whether the note number specified in the **`noteMessage`** is a valid note within the range of possible piano keys, specified in constants **`FIRST_NOTE`** and **`MAX_KEYS`** (line 52).

If the command is a **`ShortMessage`**.**`NOTE_ON`** command and is within range of the piano keys, the synthesizer receives the specified note message (lines 497–498) and the corresponding piano key's color becomes red for the duration of the event (line 494). Line 491 obtains the corresponding piano button number (**`lastKeyOn`**) that should become red.

If the command is **ShortMessage.NOTE_OFF** and is within the allowable piano key range (lines 513–517), lines 520–521 change the background of the specified piano key back to white. Lines 524-525 send the **ShortMessage** to the synthesizer so that the note will stop sounding. Because not all **NOTE_ON ShortMessage**s are followed by a **NOTE_OFF ShortMessage** as one would expect, the program needs to change the last **NOTE_ON** key back to its original color at the time of the next event. For that purpose method **noteAction** assigns a **lastKeyOn** value to the last piano button invoked. The **lastKeyOn** object initialized to **-1** remains **-1** if the **NOTE_ON** command note is out of range. This limits access only to keys in range of our simulated keyboard. When **pianoTimer** reaches the next event, the program changes the background of the last "pressed" piano key back to white (lines 447–449).

When the program finishes executing method **noteAction**, line 452 invokes **MidiData** method **goNextEvent** to transition to the next event in the track. Every time the handler's **actionPerformed** method finishes loading the next event, line 455 determines whether the next event is the last event in the track by invoking **MidiData** method **isTrackEnd**, assuming that the last event is the end-of-track **MetaEvent**. If the next event is the last event, lines 457–459 change the background color of the last "pressed" key to white and line 461 stops the **pianoTimer**. Lines 463–465 re-enable buttons that were disabled during the "piano player" feature.

22.8 Internet and World Wide Web Resources

This section presents several Internet and Web resources for the Java Media Framework and other multimedia related sites.

java.sun.com/products/java-media/jmf/
The *Java Media Framework home page* on the Java Web site. Here you can download the latest Sun implementation of the JMF. The site also contains the documentation for the JMF.

www.nasa.gov/gallery/index.html
The *NASA multimedia gallery* contains a wide variety of images, audio clips and video clips that you can download and use to test your Java multimedia programs.

sunsite.sut.ac.jp/multimed/
The *Sunsite Japan Multimedia Collection* also provides a wide variety of images, audio clips and video clips that you can download for educational purposes.

www.anbg.gov.au/anbg/index.html
The *Australian National Botanic Gardens* Web site provides links to sounds of many animals. Try the *Common Birds* link.

www.midi.com
Midi.com is a MIDI resource site with a MIDI search engine, links to other MIDI sites, a list of MIDI-related books and other MIDI information.

www.streamingmedia.com
Streamingmedia.com provides many articles of the streaming media industry and technical information streaming media technology.

www.harmony-central.com/MIDI/
Harmony Central's MIDI resources section contains many useful MIDI documents, links and forums that can be useful for a MIDI programmer.

22.9 (Optional Case Study) Thinking About Objects: Animation and Sound in the View

This case study has focused mainly on the elevator system model. Now that we have completed our design of the model, we turn our attention to the *view*, which provides the visual presentation of the model. In our case study, the view—called **`ElevatorView`**—is a **`JPanel`** object containing other **`JPanel`** "child" objects, each representing a unique object in the model (e.g. a **`Person`**, a **`Button`**, the **`Elevator`**). Class **`ElevatorView`** is the largest class in the case study. In this section, we discuss the graphics and sound classes used by class **`ElevatorView`**. We present and explain the remainder of the code in this class in Appendix I.

In Section 3.7, we constructed a class diagram for our model by locating the nouns and noun phrases from the problem statement of Section 2.7. We ignored several of these nouns, because they were not associated with the model. Now, we list the nouns and nouns phrases that apply to displaying the model:

- display
- audio
- elevator music

The noun "display" corresponds to the view, or the visual presentation of the model. As described in Section 13.17, class **`ElevatorView`** aggregates several classes comprising the view. The "audio" refers to the sound effects that our simulation generates when various actions occur—we create class **`SoundEffects`** to generate these sound effects. The phrase "elevator music" refers to the music played as the **`Person`** rides in the **`Elevator`**—we create class **`ElevatorMusic`** to play this music.

The view must display all objects in the model. We create class **`ImagePanel`** to represent stationary objects in the model, such as the **`ElevatorShaft`**. We create class **`MovingPanel`**, which extends **`ImagePanel`**, to represent moving objects, such as the **`Elevator`**. Lastly, we create class **`AnimatedPanel`**, which extends **`MovingPanel`**, to represent moving objects whose corresponding images change continuously, such as a **`Person`** (we use several frames of animation to show the **`Person`** walking then pressing a button). Using these classes, we present the class diagram of the view for our simulation in Fig. 22.9.

The notes indicate the roles that the classes play in the system. According to the class diagram, class **`ElevatorView`** represents the view, classes **`ImagePanel`**, **`MovingPanel`** and **`AnimatedPanel`** relate to the graphics, and classes **`SoundEffects`** and **`ElevatorMusic`** relate to the audio. Class **`ElevatorView`** contains several instances of classes **`ImagePanel`**, **`MovingPanel`** and **`AnimatedPanel`** and one instance each of classes **`SoundEffects`** and **`ElevatorMusic`**. In Appendix I, we associate each object in the model with a corresponding class in the view.

In this section, we discuss classes **`ImagePanel`**, **`MovingPanel`** and **`AnimatedPanel`** to explain the graphics and animation. We then discuss classes **`SoundEffects`** and **`ElevatorMusic`** to explain the audio functionality.

ImagePanel

The **`ElevatorView`** uses objects from **`JPanel`** subclasses to represent and display each object in the model (such as the **`Elevator`**, a **`Person`**, the **`ElevatorShaft`**, etc.).

Class **ImagePanel** (Fig. 22.10) is a **JPanel** subclass capable of displaying an image at a given screen position. The **ElevatorView** uses **ImagePanel** objects to represent stationary objects in the model, such as the **ElevatorShaft** and the two **Floor**s. Class **ImagePanel** contains an integer attribute—**ID** (line 16)—that defines a unique identifier used to track the **ImagePanel** in the view if necessary. This tracking is useful when several objects of the same class exist in the model, such as several **Person** objects. Class **ImagePanel** contains **Point2D.Double** object **position** (line 19) to represent the **ImagePanel** screen position. We will see later that **MovingPanel**, which extends **ImagePanel**, defines velocity with **double**s—using type **double** yields a highly accurate velocity and position. We cast the **position** coordinates to **int**s to place the **ImagePanel** on screen (Java represents screen coordinates as **int**s) in method **setPosition** (lines 90–94). Class **ImagePanel** also contains an **ImageIcon** object called **imageIcon** (line 22)—method **paintComponent** (lines 54–60) displays **imageIcon** on screen. Lines 41–42 initialize **imageIcon** using a **String** parameter holding the name of the image. Lastly, class **ImagePanel** contains **Set panelChildren** (line 25) that stores any child objects of class **ImagePanel** (or objects of a subclass of **ImagePanel**). The child objects are displayed on top of their parent **ImagePanel**—for example, a **Person** riding inside the **Elevator**. The first method **add** (lines 63–67) appends an object to **panelChildren**. The second method **add** (lines 70–74) inserts an object into **panelChildren** at a given index. Method **setIcon** (lines 84–87) sets **imageIcon** to a new image. Objects of class **AnimatedPanel** use method **setIcon** repeatedly to change the image displayed, which causes the animation for the view—we discuss animation later in the section.

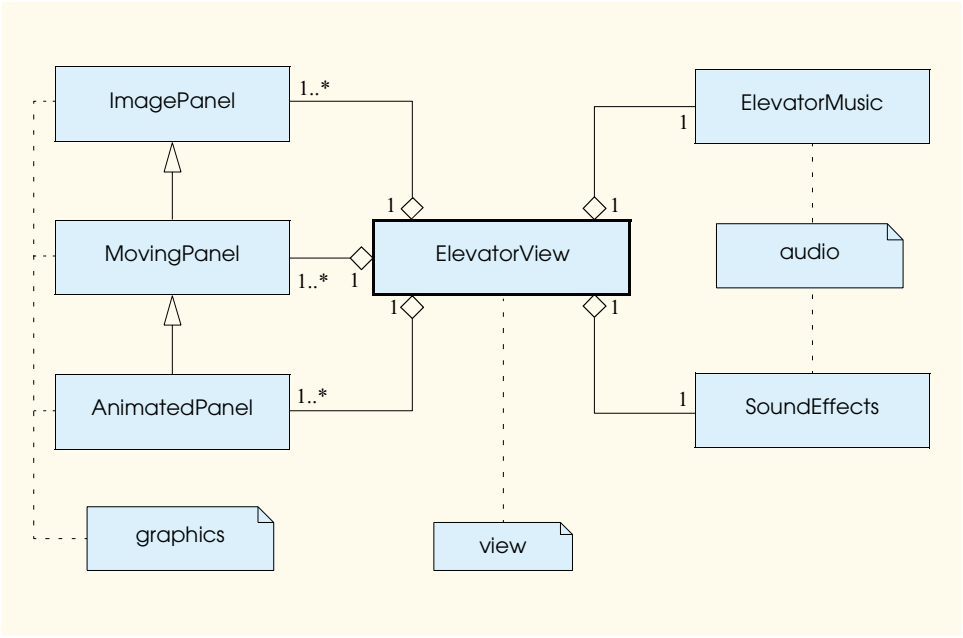

Fig. 22.9 Class diagram of elevator simulation view.

```
1  // ImagePanel.java
2  // JPanel subclass for positioning and displaying ImageIcon
3  package com.deitel.jhtp4.elevator.view;
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.geom.*;
8  import java.util.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class ImagePanel extends JPanel {
14
15    // identifier
16    private int ID;
17
18    // on-screen position
19    private Point2D.Double position;
20
21    // imageIcon to paint on screen
22    private ImageIcon imageIcon;
23
24    // stores all ImagePanel children
25    private Set panelChildren;
26
27    // constructor initializes position and image
28    public ImagePanel( int identifier, String imageName )
29    {
30       super( null ); // specify null layout
31       setOpaque( false ); // make transparent
32
33       // set unique identifier
34       ID = identifier;
35
36       // set location
37       position = new Point2D.Double( 0, 0 );
38       setLocation( 0, 0 );
39
40       // create ImageIcon with given imageName
41       imageIcon = new ImageIcon(
42          getClass().getResource( imageName ) );
43
44       Image image = imageIcon.getImage();
45       setSize(
46          image.getWidth( this ), image.getHeight( this ) );
47
48       // create Set to store Panel children
49       panelChildren = new HashSet();
50
51    } // end ImagePanel constructor
52
```

Fig. 22.10 Class **ImagePanel** represents and displays a stationary object from the model (part 1 of 3).

```
53     // paint Panel to screen
54     public void paintComponent( Graphics g )
55     {
56        super.paintComponent( g );
57
58        // if image is ready, paint it to screen
59        imageIcon.paintIcon( this, g, 0, 0 );
60     }
61
62     // add ImagePanel child to ImagePanel
63     public void add( ImagePanel panel )
64     {
65        panelChildren.add( panel );
66        super.add( panel );
67     }
68
69     // add ImagePanel child to ImagePanel at given index
70     public void add( ImagePanel panel, int index )
71     {
72        panelChildren.add( panel );
73        super.add( panel, index );
74     }
75
76     // remove ImagePanel child from ImagePanel
77     public void remove( ImagePanel panel )
78     {
79        panelChildren.remove( panel );
80        super.remove( panel );
81     }
82
83     // sets current ImageIcon to be displayed
84     public void setIcon( ImageIcon icon )
85     {
86        imageIcon = icon;
87     }
88
89     // set on-screen position
90     public void setPosition( double x, double y )
91     {
92        position.setLocation( x, y );
93        setLocation( ( int ) x,  ( int ) y );
94     }
95
96     // return ImagePanel identifier
97     public int getID()
98     {
99        return ID;
100    }
101
102    // get position of ImagePanel
103    public Point2D.Double getPosition()
104    {
```

Fig. 22.10 Class **ImagePanel** represents and displays a stationary object from the model (part 2 of 3).

```
105         return position;
106      }
107
108      // get imageIcon
109      public ImageIcon getImageIcon()
110      {
111         return imageIcon;
112      }
113
114      // get Set of ImagePanel children
115      public Set getChildren()
116      {
117         return panelChildren;
118      }
119   }
```

Fig. 22.10 Class **ImagePanel** represents and displays a stationary object from the model (part 3 of 3).

MovingPanel

Class **MovingPanel** (Fig. 22.11) is an **ImagePanel** subclass capable of changing its screen position according to its **xVelocity** and **yVelocity** (lines 20–21). The **ElevatorView** uses **MovingPanel** objects to represent moving objects from the model, such as the **Elevator**.

```
1  // MovingPanel.java
2  // JPanel subclass with on-screen moving capabilities
3  package com.deitel.jhtp4.elevator.view;
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.geom.*;
8  import java.util.*;
9
10 // Java extension packages
11 import javax.swing.*;
12
13 public class MovingPanel extends ImagePanel {
14
15    // should MovingPanel change position?
16    private boolean moving;
17
18    // number of pixels MovingPanel moves in both x and y values
19    // per animationDelay milliseconds
20    private double xVelocity;
21    private double yVelocity;
22
```

Fig. 22.11 Class **MovingPanel** represents and displays a moving object from the model (part 1 of 3).

```
23     // constructor initializes position, velocity and image
24     public MovingPanel( int identifier, String imageName )
25     {
26        super( identifier, imageName );
27
28        // set MovingPanel velocity
29        xVelocity = 0;
30        yVelocity = 0;
31
32     } // end MovingPanel constructor
33
34     // update MovingPanel position and animation frame
35     public void animate()
36     {
37        // update position according to MovingPanel velocity
38        if ( isMoving() ) {
39           double oldXPosition = getPosition().getX();
40           double oldYPosition = getPosition().getY();
41
42           setPosition( oldXPosition + xVelocity,
43              oldYPosition + yVelocity );
44        }
45
46        // update all children of MovingPanel
47        Iterator iterator = getChildren().iterator();
48
49        while ( iterator.hasNext() ) {
50           MovingPanel panel = ( MovingPanel ) iterator.next();
51           panel.animate();
52        }
53     } // end method animate
54
55     // is MovingPanel moving on screen?
56     public boolean isMoving()
57     {
58        return moving;
59     }
60
61     // set MovingPanel to move on screen
62     public void setMoving( boolean move )
63     {
64        moving = move;
65     }
66
67     // set MovingPanel x and y velocity
68     public void setVelocity( double x, double y )
69     {
70        xVelocity = x;
71        yVelocity = y;
72     }
73
```

Fig. 22.11 Class **MovingPanel** represents and displays a moving object from the model (part 2 of 3).

```
74      // return MovingPanel x velocity
75      public double getXVelocity()
76      {
77         return xVelocity;
78      }
79
80      // return MovingPanel y velocity
81      public double getYVelocity()
82      {
83         return yVelocity;
84      }
85   }
```

Fig. 22.11 Class **MovingPanel** represents and displays a moving object from the model (part 3 of 3).

Method **animate** (lines 35–53) moves the **MovingPanel** according to the current values of attributes **xVelocity** and **yVelocity**. If **boolean** variable **moving** (line 16) is **true**, lines 38–44 use attributes **xVelocity** and **yVelocity** to determine the next location for the **MovingPanel**. Lines 47–52 repeat the process for any children. In our simulation, **ElevatorView** invokes method **animate** and method **paintComponent** of class **ImagePanel** every 50 milliseconds. These rapid, successive calls move the **MovingPanel** object.

AnimatedPanel

Class **AnimatedPanel** (Fig. 22.12), which extends class **MovingPanel**, represents an animated object from the model (i.e., moving objects whose corresponding image changes continuously), such as a **Person**. The **ElevatorView** animates an **AnimatedPanel** object by changing the image associated with **imageIcon**.

```
1   // AnimatedPanel.java
2   // MovingPanel subclass with animation capabilities
3   package com.deitel.jhtp4.elevator.view;
4
5   // Java core packages
6   import java.awt.*;
7   import java.util.*;
8
9   // Java extension packages
10  import javax.swing.*;
11
12  public class AnimatedPanel extends MovingPanel {
13
14     // should ImageIcon cycle frames
15     private boolean animating;
16
17     // frame cycle rate (i.e., rate advancing to next frame)
18     private int animationRate;
```

Fig. 22.12 Class **AnimatedPanel** represents and displays an animated object from the model (part 1 of 4).

```
19       private int animationRateCounter;
20       private boolean cycleForward = true;
21
22       // individual ImageIcons used for animation frames
23       private ImageIcon imageIcons[];
24
25       // storage for all frame sequences
26       private java.util.List frameSequences;
27       private int currentAnimation;
28
29       // should loop (continue) animation at end of cycle?
30       private boolean loop;
31
32       // should animation display last frame at end of animation?
33       private boolean displayLastFrame;
34
35       // helps determine next displayed frame
36       private int currentFrameCounter;
37
38       // constructor takes array of filenames and screen position
39       public AnimatedPanel( int identifier, String imageName[] )
40       {
41          super( identifier, imageName[ 0 ] );
42
43          // creates ImageIcon objects from imageName string array
44          imageIcons = new ImageIcon[ imageName.length ];
45
46          for ( int i = 0; i < imageIcons.length; i++ ) {
47             imageIcons[ i ] = new ImageIcon(
48                getClass().getResource( imageName[ i ] ) );
49          }
50
51          frameSequences = new ArrayList();
52
53       } // end AnimatedPanel constructor
54
55       // update icon position and animation frame
56       public void animate()
57       {
58          super.animate();
59
60          // play next animation frame if counter > animation rate
61          if ( frameSequences != null && isAnimating() ) {
62
63             if ( animationRateCounter > animationRate ) {
64                animationRateCounter = 0;
65                determineNextFrame();
66             }
67             else
68                animationRateCounter++;
69          }
70       } // end method animate
```

Fig. 22.12 Class **AnimatedPanel** represents and displays an animated object from the model (part 2 of 4).

```
71
72     // determine next animation frame
73     private void determineNextFrame()
74     {
75        int frameSequence[] =
76           ( int[] ) frameSequences.get( currentAnimation );
77
78        // if no more animation frames, determine final frame,
79        // unless loop is specified
80        if ( currentFrameCounter >= frameSequence.length ) {
81           currentFrameCounter = 0;
82
83           // if loop is false, terminate animation
84           if ( !isLoop() ) {
85
86              setAnimating( false );
87
88              if ( isDisplayLastFrame() )
89
90                 // display last frame in sequence
91                 currentFrameCounter = frameSequence.length - 1;
92           }
93        }
94
95        // set current animation frame
96        setCurrentFrame( frameSequence[ currentFrameCounter ] );
97        currentFrameCounter++;
98
99     } // end method determineNextFrame
100
101    // add frame sequence (animation) to frameSequences ArrayList
102    public void addFrameSequence( int frameSequence[] )
103    {
104       frameSequences.add( frameSequence );
105    }
106
107    // ask if AnimatedPanel is animating (cycling frames)
108    public boolean isAnimating()
109    {
110       return animating;
111    }
112
113    // set AnimatedPanel to animate
114    public void setAnimating( boolean animate )
115    {
116       animating = animate;
117    }
118
119    // set current ImageIcon
120    public void setCurrentFrame( int frame )
121    {
122       setIcon( imageIcons[ frame ] );
```

Fig. 22.12 Class **AnimatedPanel** represents and displays an animated object from the model (part 3 of 4).

```
123     }
124
125     // set animation rate
126     public void setAnimationRate( int rate )
127     {
128        animationRate = rate;
129     }
130
131     // get animation rate
132     public int getAnimationRate()
133     {
134        return animationRate;
135     }
136
137     // set whether animation should loop
138     public void setLoop( boolean loopAnimation  )
139     {
140        loop = loopAnimation;
141     }
142
143     // get whether animation should loop
144     public boolean isLoop()
145     {
146        return loop;
147     }
148
149     // get whether to display last frame at animation end
150     private boolean isDisplayLastFrame()
151     {
152        return displayLastFrame;
153     }
154
155     // set whether to display last frame at animation end
156     public void setDisplayLastFrame( boolean displayFrame )
157     {
158        displayLastFrame = displayFrame;
159     }
160
161     // start playing animation sequence of given index
162     public void playAnimation( int frameSequence )
163     {
164        currentAnimation = frameSequence;
165        currentFrameCounter = 0;
166        setAnimating( true );
167     }
168  }
```

Fig. 22.12 Class **AnimatedPanel** represents and displays an animated object from the model (part 4 of 4).

Class **AnimatedPanel** chooses the **ImageIcon** object to be drawn on screen from among several **ImageIcon** objects stored in array **imageIcons** (line 23). Class **AnimatedPanel** determines the **ImageIcon** object according to a series of *frame sequence* references, stored in **List frameSequences** (line 26). A frame sequence is an array of

integers holding the proper sequence to display the **ImageIcon** objects; specifically, each integer represents the index of an **ImageIcon** object in **imageIcons**. Figure 22.13 demonstrates the relationship between **imageIcons** and **frameSequences** (this is not a diagram of the UML). For example, frame sequence number

```
2 = { 2, 1, 0 }
```

refers to { **imageIcon[2]**, **imageIcon[1]**, **imageIcon[0]** }, which yields the image sequence { **C**, **B**, **A** }. In the view, each image is a unique **.png** file. Method **addFrameSequence** (lines 102–105) adds a frame sequence to **List frameSequences**. Method **playAnimation** (lines 162–167) starts the animation associated with the parameter **frameSequence**. For example, assume an **AnimatedPanel** object called **personAnimatedPanel** in class **ElevatorView**. The code segment

```
animatedPanel.playAnimation( 1 );
```

would generate the { **A**, **B**, **D**, **B**, **A** } image sequence using Fig. 22.13 as a reference.

Method **animate** (lines 56–70) overrides method **animate** of superclass **MovingPanel**. Lines 61–69 determine the next frame of animation depending on attribute **animationRate**, which is inversely proportional to the animation speed—a higher value for **animationRate** yields a slower frame rate. For example, if **animationRate** is 5, **animate** moves to the next frame of animation every fifth time it is invoked. Using this logic, the animation rate maximizes when **animationRate** has a value of 1, because the next frame is determined each time **animate** runs.

Method **animate** calls **determineNextFrame** (lines 73–99) to determine the next frame (image) to display—specifically, it calls method **setCurrentFrame** (lines 120–123), which sets **imageIcon** (the current image displayed) to the image returned from the current frame sequence. Lines 84–92 of **determineNextFrame** are used for "looping" purposes in the animation. If **loop** is **false**, the animation terminates after one iteration. The last frame in the sequence is displayed if **displayLastFrame** is **true**, and the first frame in the sequence is displayed if **displayLastFrame** is **false**. We explain in greater detail in Appendix I how **ElevatorView** uses **displayLastFrame** for the **Person** and **Door AnimatedPanel**s to ensure the proper display of the image. If **loop** is **true**, the animation repeats until stopped explicitly.

Sound Effects

We now discuss how we generate audio in our elevator simulation. We divide audio functionality between two classes—**SoundEffects** and **ElevatorMusic**. (these classes are not part of the Java packages, although **SoundEffects** uses the **java.applet** package and **ElevatorMusic** uses the **javax.sound.midi** package). Class **SoundEffects** (Figure 22.14) transforms audio (**.au**) and wave (**.wav**) files, containing such sounds as the bell ring and the person's footsteps, into **java.applet.AudioClip** objects. In Appendix I, we list all **AudioClip**s used in our simulation. Class **ElevatorMusic** (Fig. 22.15) plays a **MIDI** (**.mid**) file when the person rides the elevator. The **ElevatorView** object will play the **AudioClip** and **ElevatorMusic** objects to generate sound. All sound files are in the directory structure

```
com/deitel/jhtp4/elevator/view/sounds
```

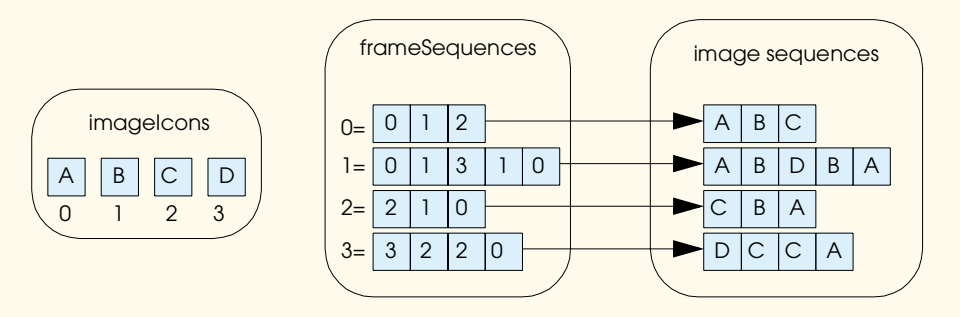

Fig. 22.13 Relationship between array **imageIcons** and **List frameSequences**.

(i.e., in the **sounds** directory where the classes for the view are located in the file system). In our simulation, we use sounds and **MIDI** files provided free for download by Microsoft at the Web site:

msdn.microsoft.com/downloads/default.asp

To download these sounds, click on "Graphics and Multimedia," "Multimedia (General)," then "Sounds."

```
1  // SoundEffects.java
2  // Returns AudioClip objects
3  package com.deitel.jhtp4.elevator.view;
4
5  // Java core packages
6  import java.applet.*;
7
8  public class SoundEffects {
9
10    // location of sound files
11    private String prefix = "";
12
13    public SoundEffects() {}
14
15    // get AudioClip associated with soundFile
16    public AudioClip getAudioClip( String soundFile )
17    {
18       try {
19          return Applet.newAudioClip( getClass().getResource(
20             prefix + soundFile ) );
21       }
22
23       // return null if soundFile does not exist
24       catch ( NullPointerException nullPointerException ) {
25          return null;
26       }
27    }
```

Fig. 22.14 Class **SoundEffects** return **AudioClip** objects (part 1 of 2).

```
28
29       // set prefix for location of soundFile
30       public void setPathPrefix( String string )
31       {
32          prefix = string;
33       }
34    }
```

Fig. 22.14 Class **SoundEffects** return **AudioClip** objects (part 2 of 2).

Class **SoundEffects** contains method **getAudioClip** (lines 16–27), which uses **static** method **newAudioClip** (of class **java.applet.Applet**) to return an **AudioClip** object using the **soundFile** parameter. Method **setPrefix** (lines 30–33) allows for changing the directory of a sound file (useful if we want to partition our sounds among several directories).

```
1  // ElevatorMusic.java
2  // Allows for MIDI playing capabilities
3  package com.deitel.jhtp4.elevator.view;
4
5  // Java core packages
6  import java.io.*;
7  import java.net.*;
8
9  // Java extension packages
10 import javax.sound.midi.*;
11
12 public class ElevatorMusic implements MetaEventListener {
13
14    // MIDI sequencer
15    private Sequencer sequencer;
16
17    // should music stop playing?
18    private boolean endOfMusic;
19
20    // sound file name
21    private String fileName;
22
23    // sequence associated with sound file
24    private Sequence soundSequence;
25
26    // constructor opens a MIDI file to play
27    public ElevatorMusic( String file )
28    {
29       // set sequencer
30       try {
31          sequencer = MidiSystem.getSequencer();
32          sequencer.addMetaEventListener( this );
33          fileName = file;
34       }
```

Fig. 22.15 Class **ElevatorMusic** plays music when a **Person** rides in the **Elevator** (part 1 of 3).

```
35
36          // handle exception if MIDI is unavailable
37          catch ( MidiUnavailableException midiException ) {
38             midiException.printStackTrace();
39          }
40       } // end ElevatorMusic constructor
41
42       // open music file
43       public boolean open()
44       {
45          try {
46
47             // get URL for media file
48             URL url = getClass().getResource( fileName );
49
50             // get valid MIDI file
51             soundSequence = MidiSystem.getSequence ( url );
52
53             // open sequencer for specified file
54             sequencer.open();
55             sequencer.setSequence( soundSequence );
56          }
57
58          // handle exception if URL does not exist
59          catch ( NullPointerException nullPointerException ) {
60             nullPointerException.printStackTrace();
61             return false;
62          }
63
64          // handle exception if MIDI data is invalid
65          catch ( InvalidMidiDataException midiException ) {
66             midiException.printStackTrace();
67             soundSequence = null;
68             return false;
69          }
70
71          // handle IO exception
72          catch ( java.io.IOException ioException ) {
73             ioException.printStackTrace();
74             soundSequence = null;
75             return false;
76          }
77
78          // handle exception if MIDI is unavailable
79          catch ( MidiUnavailableException midiException ) {
80             midiException.printStackTrace();
81             return false;
82          }
83
84          return true;
85       }
86
```

Fig. 22.15 Class **ElevatorMusic** plays music when a **Person** rides in the **Elevator** (part 2 of 3).

```
87       // play MIDI track
88       public void play()
89       {
90          sequencer.start();
91          endOfMusic = false;
92       }
93
94       // get sequencer
95       public Sequencer getSequencer()
96       {
97          return sequencer;
98       }
99
100      // handle end of track
101      public void meta( MetaMessage message )
102      {
103         if ( message.getType() == 47 ) {
104            endOfMusic = true;
105            sequencer.stop();
106         }
107      }
108   }
```

Fig. 22.15 Class **ElevatorMusic** plays music when a **Person** rides in the **Elevator** (part 3 of 3).

As we discussed in Section 22.7, Java 2 offers ***MIDI*** support. Class **ElevatorMusic** uses the **javax.sound.midi** package to play the **MIDI** file. Class **ElevatorMusic** listens for a **MetaMessage** event from the **MIDI** file. The sequencer generates a **MetaMessage** event. Class **ElevatorMusic**'s constructor (lines 27–40) of the constructor initializes the system's **MIDI** sequencer and registers class **ElevatorMusic** for **MetaMessage** events from the sequencer. Method **open** (lines 43–85) opens the sequencer for a specified file and ensures the **MIDI** data is valid. Method **play** (lines 88–92) starts the sequencer and plays the **MIDI** file.

Conclusion

You have completed a substantial object-oriented design (OOD) process that was intended to help prepare you for the challenges of "industrial-strength" projects. We hope you have found the optional "Thinking About Objects" sections informative and useful as a supplement to the material presented in the chapters. In addition, we hope you have enjoyed the experience designing the elevator system using the UML. The worldwide software industry has adopted the UML as the *de facto* standard for modeling object-oriented software.

Although we have completed the design process, we have merely "scratched the surface" of the implementation process. We urge you to read Appendices G, H and I on the accompanying CD, which fully implement the design. These appendices translate the UML diagrams into a 3,465-line Java program for the elevator simulation. In these appendices, we present all code that we did not cover in the "Thinking About Objects" sections and a complete "walkthrough" of this code.

1. Appendix G presents the Java files that implement events and listeners
2. Appendix H presents the Java files that implement the model

3. Appendix I presents the Java files that implement the view

We do not introduce an abundance of new material or UML design in these appendices—they simply serve to implement the UML-based diagram we have presented in previous chapters into a fully functional program. Studying the implementation in the appendices should hone the programming skills you have developed throughout the book and reinforce your understanding of the design process.

SUMMARY

- Through the JMF API, programmers can create Java applications that play, edit, stream and capture many popular and high-quality media types.
- JMF 2.1.1 supports popular media file types such as Microsoft Audio/Video Interleave (**`.avi`**), Macromedia Flash 2 movies (**`.swf`**), MPEG Layer 3 Audio (**`.mp3`**), Musical Instrument Digital Interface (MIDI; **`.mid`**), MPEG-1 videos (**`.mpeg`**, **`.mpg`**), QuickTime (**`.mov`**) and Sun Audio (**`.au`**).
- The Java Sound API and its extensive sound processing capabilities. Java Sound is a lower-level API that supports many of the JMF's internal audio capabilities.
- A **`Player`** is a type of **`Controller`** in JMF that can process and play media clips. Playing media clips with interface **`Player`** can be as simple as specifying the media source, creating a **`Player`** for the media, obtaining the output media and controls GUI components from **`Player`** and displaying them. In addition, **`Player`**s can access media from a capture device such as a microphone and from a Real-time transport protocol (RTP) stream—a stream of bytes sent over a network that can be buffered and played on the client computer.
- Play media involves accessing the media, creating a **`Controller`** for the media and outputting the media. Before outputting the media, there is the option of formatting the media.
- JMF provides lightweight video renderers compatible with Swing GUI components using **`Manager`** method **`setHint`** with parameter **`Manager.LIGHTWEIGHT_RENDERER`** and **`Boolean.TRUE`**.
- A **`MediaLocator`** is similar to a **`URL`**, but it also supports RTP streaming session addresses and capture device locations.
- Invoke **`Manager`** method **`createPlayer`** to create a **`Player`** object that references a media player. Method **`createPlayer`** opens the specified media source and determines the appropriate player for the media source. A **`NoPlayerException`** occurs if no appropriate player can be found for the media clip.
- Class **`Manager`** provides **`static`** methods that enable programs to access to most JMF resources.
- Throughout the media-handling process, **`Player`**s generate **`ControllerEvent`**s that **`ControllerListeners`** listen for. Class **`ControllerAdapter`**, which implements methods of interface **`ControllerListener`**.
- **`Controller`**s use state transitions to confirm their position in the media processing algorithm.
- **`Player`**'s **`realize`** method to confirm all resources necessary to play media. Method **`realize`** places the **`Player`** in a **`Realizing`** state where the player interacts with its media sources. When a **`Player`** completes realizing, it generates a **`RealizedCompleteEvent`**—a type of **`ControllerEvent`** that occurs when a **`Player`** completes its transition to state **`Realized`**.
- **`Player`** method **`prefetch`** causes the **`Player`** to obtain hardware resources for playing the media and begin buffering the media data. Buffering the media data reduces the delay before the media clip plays because media reading can take a long time.

- Invoke **Player** method **getVisualComponent** method to obtain the visual component of a video. Invoke **Player** method **getControlPanelComponent** to return the player's GUI controls.
- When the media clip ends, the **Player** generates a **ControllerEvent** of type **EndOfMediaEvent**.
- **Player** method **setMediaTime** sets the position of the media to a specific time in the media.
- Invoking **Player** method **start** starts media playback. It also buffers and realizes the player if that has not been done.
- Capture devices such as microphones have the ability to convert analog media into digitized media. This type of media is known as captured media.
- Class **DataSource** abstracts the media source to allow a program to manipulate it and provides a connection to the media source.
- Interface **Processor** allows a program to manipulate data at the various processing stages. It extends interface **Player** and provides more control over media processing.
- Monitoring allows you to hear or see the captured media as it is captured and saved. A **MonitorControl** and other control objects obtained from **Controller** by invoking method **getControl**.
- JMF provides class **Format** to describe the attributes of a media format, such as the sampling rate (which controls the quality of the sound) and whether the media should be in stereo or mono format. **FormatControl** objects that allow us to format objects that support format controls.
- Class **CaptureDeviceManager** enables a program to access capture device information.
- A **CaptureDeviceInfo** object provides the essential information necessary of a capture device's **DataSource**.
- Invoke **Manager** method **createDataSource** to obtain the **DataSource** object that of that media location.
- **Manager** method **createRealizedProcessor** creates a realized **Processor** object that can start processing media data. The method requires as an argument a **ProcessorModel** object containing the specifications of the **Processor**.
- Use a **ContentDescriptor** to describe the content-type of output from a **Processor**. **FileTypeDescriptor** specifies the a file media content.
- Call **Processor** method **getTrackControls** to get each track's controls.
- An object that implements interface **DataSink** enables media data to be output to a specific location—most commonly a file. **Manager** method **createDataSink** receives the **DataSource** and **MediaLocator** as arguments to create a **DataSink** object.
- Register a **DataSinkListener** to listen for **DataSinkEvent***s* generated by a **DataSink**. A program can call **DataSinkListener** method **dataSinkUpdate** when each **DataSinkEvent** occurs. A **DataSink** causes an **EndOfStreamEvent** when the capture stream connection closes
- Streaming media refers to media that is transferred from a server to a client in a continuous stream of bytes. Streaming media technology loads media data into buffers before displaying media.
- JMF provides a streaming media package that enables Java applications to send and receive streams of media in the formats discussed earlier in this chapter. JMF uses the industry-standard Real-Time Transport Protocol (RTP) to control media transmission. RTP is designed specifically to transmit real-time media data.
- Use a **DataSink** or a **RTPManager** to stream media. **RTPManager**s provide more control and versatility for the transmission. If an application sends multiple streams, the application must have

an **RTPManager** for each separate streaming session. Both require the **DataSource** obtained from **Processor**'s **getOutput** method.

- The URL of RTP streams is in format: **rtp://**<*host*>**:**<*port*>**/**<*contentType*>
- Formatting the media can only be done when the **Processor** has been configured. To notify the program when it completes **Processor** configuration, register a **ControllerListener** to notify the program that it has completed configuring. A **ConfigureCompleteEvent** occurs when **Processor** completes configuration.
- **Processor** method **setContentDescriptor** sets the stream to an RTP-enabled format with **ContentDescriptor.RAW_RTP** parameter.
- **TrackControl** interface allow the formats of the media tracks to be set.
- **SessionAddress** contains an IP addresses and port number used in the streaming process. **RTPManger**s use **SessionAddress**es to stream media.
- Invoke **RTPManager** method **initialize** to initialize the local streaming session with the local session address as the parameter. Invoke **RTPManager** method **addTarget** to add the destination session address as the client recipient of the media stream. To stream media to multiple clients, call **RTPManger** method **addTarget** for each destination address.
- **RTPManager** method **removeTargets** closes streaming to specific destinations. **RTPManager** method **dispose** release the resources held by the RTP sessions
- The Java Sound API provides classes and interfaces for accessing, manipulating and playing Musical Instrumental Data Interface (MIDI) and sampled audio.
- A sound card is required to play audio with Java Sound. Java Sound throws exceptions when it accesses audio system resources to process audio on a computer that does not have a sound card.
- Programmers can use package **javax.sound.sampled** to play sampled audio file formats, which includes Sun Audio (**.au**), Wave (**.wav**) and AIFF (**.aiff**).
- To process audio data, we can to use a **Clip** line that allows the flow of raw digital data to audio data we can listen to.
- An **AudioInputStream** object to point to the audio stream. Class **AudioInputStream** (a subclass of **InputStream**) provides access to the audio stream contents.
- The length of video and audio clips is measured in frames. Each frame represents data at a specific time interval in the audio file.
- The algorithm for playing sampled audio supported by Java Sound is as follows: obtain an **AudioInputStream** from an audio file, obtain a formatted **Clip** line, load the **AudioInputStream** into the **Clip** line, start the data flow in the **Clip** line.
- All **Line**s generate **LineEvent***s* that can be handled by **LineListener**. The first step to sampled audio playback involves obtaining the audio stream from an audio file.
- Class **AudioSystem** enables a program to access many audio system resources required to play and manipulate sound files.
- Method **getAudioInputStream** throws an **UnsupportedAudioFileException** if the specified sound file is a non-audio file or contains a sound clip format that is not supported by Java Sound.
- Method **getLine** requires a **Line.Info** object as an argument, which specifies the attributes of the line the **AudioSystem** should obtain.
- We can use a **DataLine.Info** object that specifies a **Clip** data line, a general encoding format and a buffer range. We need to specify a buffer range so the program can determine the best buffer size given a preferred range.

- **DataLine.Info** objects specify information about a **Clip** line, such as the formats supported by the **Clip**. The **DataLine.Info** object constructor receives as arguments the **Line** class, the line's supported **AudioFormat**s, the minimum buffer size and the maximum buffer size in bytes.
- **AudioSystem** method **getLine** and **Clip** method **open** throw **LineUnavailableExceptions** if another application is using the requested audio resource. **Clip** method **open** also throws an **IOException** if open is unable to read the specified **AudioInputStream**.
- Invoke **Clip** method **start** to begin audio playback.
- When a **LineEvent** occurs, the program calls **LineListener** method **update** to process the event. The four **LineEvent** types are defined in class **LineEvent.Type**. The event types are **CLOSE**, **OPEN**, **START** and **STOP**.
- Method close of class **Line** stops audio activity and closes the line—which releases any audio resources obtained previously by the **Line**.
- **Clip** method **loop** can be called with parameter **Clip.LOOP_CONTINUOSLY**. to replay the audio clip forever.
- Invoking method **stop** of interface **Clip** only stops data activity in the **Line**. Invoking method **start** resumes data activity.
- MIDI (Musical Instrument Digital Interface) music can be created through a digital instrument, such as an electronic keyboard (synthesizer), or through packaged software synthesizers. A MIDI synthesizer is a device that can produce MIDI sounds and music.
- The MIDI specification provides detailed information on the formats of a MIDI file. For detailed information on MIDI and its specification, visit their official Web site at **www.midi.org**. Java Sound's MIDI package allows developers to access the data that specify the MIDI, but it does not provide support for the specification.
- Interpretation of MIDI data varies between synthesizers and will sound different with different instruments. Package **javax.sound.midi** enables program to manipulate, play and synthesize MIDI. There are three MIDI types—0 (the most common), 1 and 2. Java Sound supports MIDI files with **.mid** extensions and **.rmf** (Rich Music Format).
- Some file parsers in various operating systems are unable to interpret the MIDI file as a MIDI file that Java can play.
- MIDI playback is accomplished by a MIDI **sequencer**. Specifically, sequencers can play and manipulate a MIDI **sequence**, which is the data formula that tells a device how to handle the MIDI data.
- Often, MIDI is referred to as a sequence, because the musical data in MIDI is composed of a sequence of events. The simplicity of MIDI data enables us to view each event individually and learn the purpose of each event. The process to MIDI playback involves accessing a sequencer, loading a MIDI sequence or a MIDI file into a sequencer and starting the sequencer.
- Method **getSequence** also can obtain a MIDI sequence from a URL or an **InputStream**. Method **getSequence** throws an **InvalidMidiDataException** if the MIDI system detects an incompatible MIDI file.
- Interface **Sequencer**, which extends interface **MidiDevice** (the super-interface for all MIDI devices), represents the standard device to play MIDI data.
- **Sequencer**'s **open** method prepares to play a **Sequence**. **Sequencer** method **setSequence** loads a MIDI **Sequence** into the **Sequencer** and throws an **InvalidMidiException** if the **Sequencer** detects an unrecognizable MIDI sequence. **Sequencer** method **play** begins playing the MIDI sequence.

- A MIDI track is a recorded sequence of data; MIDIs usually contain multiple tracks. MIDI tracks are similar to CD tracks except that the music data in MIDI are played simultaneously. Class **`Track`** (package **`javax.sound.midi`**) provides access to the MIDI music data stored in the MIDI tracks.
- MIDI data in MIDI tracks are represented by MIDI events. MIDI events are the holders of the MIDI action and the time when the MIDI command should occur. There are three types of MIDI message—**`ShortMessage`**, **`SysexMessage`** and **`MetaMessage`**. **`ShortMessage`**s provide instructions, such as specific notes play, and can configure options, such when a MIDI starts. The other two less-used messages are exclusive system messages called **`SysexMessage`** and **`MetaMessages`** which may tell a device that the MIDI has reached the end of a track. This section deals exclusively with **`ShortMessage`**s that play specific notes. Each **`MidiMessage`** is encapsulated in a **`MidiEvent`** and a sequence of **`MidiEvent`**s form a MIDI track.
- Each **`MidiEvent`**'s **`getTick`** method provides the time when the event takes place (time stamp).
- **`ShortMessage`** method **`getCommand`** returns the command integer of the message. **`ShortMessage`** method **`getData1`** returns the first status byte of the message. **`ShortMessage`** method **`getData2`** returns the second status byte. The first and second status bytes vary in interpretation according to the type of command in **`ShortMessage`**.
- General MIDI recording is accomplished through a sequencer. Interface **`Sequencer`** provides simple methods for recording—assuming the transmitters and receivers of MIDI devices are "wired" correctly.
- After setting up a sequencer and an empty sequence, a **`Sequencer`** object can invoke its **`startRecording`** method to enable and start recording on the empty **`track`**. Method **`recordEnable`** of interface **`Sequencer`** takes a **`Track`** object and a channel number as the parameters to enable recording on a track.
- Method **`write`** of class **`MidiSystem`** writes the sequence to a specified file.
- An alternative method to record MIDI without having to deal with transmitters and receivers is to create events from **`ShortMessage`**s. The events should be added to a **`track`** of a **`sequence`**.
- Interface **`Synthesizer`** is a **`MidiDevice`** interface which enables access to MIDI sound generation, instruments, channel resources, and sound banks.
- A **`SoundBank`** is the container for various **`Instrument`**s, which tell the computer how to sound a specific note and are programmed algorithms of instructions. Different notes on various instruments are played through a **`MidiChannel`** on different tracks simultaneously to produce symphonic melodies.
- Acquiring any MIDI resources throws a **`MidiUnavailableException`** if the resource is unavailable.
- Invokes **`Synthesizer`**'s **`getChannels`** method to obtain all 16 channels from the synthesizer. A **`MidiChannel`** can sound a note by calling its **`noteOn`** method with the note number (0-127) and volume as parameters. **`MidiChannel`**'s **`noteOff`** method turns off a note with just the note number parameter.
- **`Synthesizer`**'s **`getAvailableInstruments`** method obtains the default instrument programs of a synthesizer. One can also import more instruments by loading a customized sound bank through method **`loadAllInstruments`** (**`SoundBank`**) in interface **`Synthesizer`**. A sound bank usually has 128 instruments. **`MidiChannel`**'s **`programChange`** method loads the desired instrument program into the synthesizer.
- Invoke **`Receiver`**'s **`send`** method with a **`MidiMessage`** and a time stamp as its parameters to send MIDI message to all its transmitters.

TERMINOLOGY

addControllerListener method of **Controller**
addDataSinkListener method of **DataSink**
addLineListener method of **Line**
addMetaEventListener method of **Sequencer**
addTarget method of **RTPManager**
AudioFormat class
AudioFormat.Encoding.PCM_SIGNED
AudioInputStream class
AudioSystem class
Boolean.TRUE
broadband
CannotRealizeException class
capture
capture device
captured media
CaptureDevice interface
CaptureDeviceInfo class
CaptureDeviceManger class
Clip interface
Clip.class
Clip.LOOP_CONTINUOUSLY
Clock interface
close method of **Controller**
close method of **Line**
close method of **MidiDevice**
configure method of **Processor**
configureComplete method of **ControllerAdapter**
ConfigureCompleteEvent class
Controller.Prefetching
Controller.Prefeteched
Controller.Realized
Controller.Realizing
Controller.Started
Controller.Stopped
ControllerAdapter class
ControllerEvent class
ControllerListener interface
createDataSink method of **Manager**
createDataSource method of **Manager**
createPlayer method of **Manager**
createProcessor method of **Manager**
createRealizedProcessor method of **Manager**
createSendStream method of **RTPManager**
createTrack method of **Sequence**
DataLine interface
DataLine.Info class
DataSink interface
DataSinkEvent class
DataSinkListener interface
dataSinkUpdate method of **DataSinkListener**
DataSource class
deleteTrack method of **Sequence**
device ports
Direct Sound
dispose method of **RTPManager**
encoding
endOfMedia method of **ControllerAdapter**
EndofMediaEvent class
EndofStreamEvent class
FileTypeDescriptor class
FileTypeDescriptor.QUICKTIME
Format class
FormatControl interface
frames
get method of **Track**
getAudioInputStream method of **AudioSystem**
getBank method of **Patch**
getChannels method of **Synthesizer**
getCommand method of **ShortMessage**
getControlComponent method of **Control**
getControlPanelComponent method of **Player**
getData1 method of **ShortMessage**
getData2 method of **ShortMessage**
getDataOutput method of **Processor**
getDeviceList method of **CaptureDeviceManager**
getFormat method of **AudioFormat**
getFormat method of **FormatControl**
getFormatControls method of **CaptureDevice**
getFrameLength method of **AudioInputStream**
getFrameSize method of **AudioFormat**
getLine method of **AudioSystem**
getLocator method of **CaptureDeviceInfo**
getMessage method of **MidiEvent**
getMidiFileTypes method of **MidiSystem**
getPatch method of **Instrument**

getProgram method of **Patch**
getReceiver method of **MidiDevice**
getResolution method of **Sequence**
getSequence method of **MidiSystem**
getSequencer method of **MidiSystem**
getSupportedFormats method of **FormatControl**
getSynthesizer method of **MidiSystem**
getTargetFormat method of **AudioSystem**
getTick method of **MidiEvent**
getTrackControls method of **Processor**
getTracks method of **Sequence**
getTransmitter method of **MidiDevice**
getType method of **LineEvent**
getVisualComponent method of **Player**
initialize method of **RTPManager**
Instrument class
InvalidMidiException class
InvalidSessionAddress class
isEnabled method of **FormatControl**
isLineSupported method of **AudioSystem**
Java Media Framework
Java Sound
javax.media package
javax.media.control package
javax.media.datasink package
javax.media.format package
javax.media.protocol package
javax.media.rtp package
javax.sound.midi package
javax.sound.sampled package
JOptionPane.CLOSED_OPTION
JOptionPane.DEFAULT_OPTION
JOptionPane.OK_OPTION
Line interface
LineEvent class
LineEvent.Type.STOP
LineListener interface
LineUnavailableException class
loop method of **Clip**
Manager class
Manger.LIGHTWEIGHT_RENDERER
media
media clip
media location
media tracks
MediaLocator class
MIDI (Musical Instrument Digital Interface)
MIDI Specification
MidiChannel interface
MidiEvent class
MidiMessage class
MidiSystem class
MidiUnavailableException class
mixers
MonitorControl interface
monitoring
MP3
MPEG-1
network ports
newInstance method of **RTPManager**
NoDataSinkException class
NoDataSourceException class
NoPlayerException class
NoProcessorException class
noteOff method of **MidiChannel**
noteOn method of **MidiChannel**
open method of **Clip**
open method of **DataSink**
open method of **MidiDevice**
output format
packetized data
Patch class
pitch
Player interface
pre-buffer
prefetchComplete method of **ControllerAdapter**
PrefetchCompleteEvent class
pre-process
Processor interface
Processor.Configured
Processor.Configuring
ProcessorModel class
propagation delay
protocol
QuickTime
realize method of **Controller**
realizeComplete method of **ControllerAdapter**
RealizeCompleteEvent class
Receiver interface
recordEnable method of **Sequencer**
removeTargets method of **RTPManager**
RMF (Rich Music Format)
RTP (Real-time Transport Protocol)
RTPManger class
SecurityException class
send method of **Receiver**
SendStream interface

Sequence class
Sequence.PPQ
Sequencer interface
SessionAddress class
SessionAddress class
SessionEvent class
SessionListener interface
setContentDescriptor method of **Processor**
setFormat method of **FormatControl**
setHint method of **Manager**
setMediaTime of **Clock**
setMessage method of **ShortMessage**
setReceiver method of **Transmitter**
setSequence method of **Sequencer**
ShortMessage class
ShortMessage.NOTE_OFF
ShortMessage.NOTE_ON
ShortMessage.PROGRAM_CHANGE
simulation
size method of **track**
SoundBank interface
start method of **DataLine**
start method of **DataSink**
start method of **Player**
start method of **SendStream**
start method of **Sequencer**
startRecord method of **Sequencer**
stop method of **DataLine**
stop method of **DataSink**
stop method of **Sequencer**
stopRecord method of **Sequencer**
streaming media
streams
synchronization
synthesis
Synthesizer interface
teleconferencing
tempo
time stamp
Track class
TrackControl interface
Transmitter interface
UnsupportedAudioFileException class
UnsupportedFormatException class
video conference
Video for Windows
write method of **MidiSystem**

SELF-REVIEW EXERCISES

22.1 Fill in the blanks in each of the following.

a) Class _____ provides access to many JMF resources.
b) In addition to locations of media files stored on the local computer, a _____ can also specify the location of capture devices and RTP sessions.
c) Class _____ provides access to sampled audio system resources while class _____ provides access to MIDI system resources.
d) An event of type _____ indicates that a **Controller** has establish communications with the media source.
e) Method **createRealizedProcessor** takes a _____ as an argument.
f) In order, the **Processor**'s states are: *Unrealized*, _____, _____, _____, _____, _____, _____ and *Started*.
g) Constant _____ specifies that the **Processor** should output media in QuickTime format.
h) To stream media, we can use a _____ or a _____.
i) _____ objects set the stream formats for capture devices.
j) Invoking **Clip** method _____ with constant _____ as an argument replays a sampled audio file continuously.
k) A MIDI _____ contains multiple tracks, which contain a sequence of MIDI _____ that each encapsulate a MIDI _____.

22.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) **Manager** method **setHint** can be used to specify that the visual component of a media clip should be rendered using lightweight GUI components.
b) A **ControllerListener** handles events generated by a **DataSink**.
c) Only objects that implement interface **Processor** can play media.

d) A **Player** cannot access media from capture devices; a **Processor** must be used for this purpose.
e) A **Clip** plays MIDI **Sequence**s.
f) MIDI playback stops automatically when the **Sequencer** reaches the end of a MIDI **Sequence**.
g) An **RTPManger** can stream an entire media file regardless of the number of tracks in the file.
h) Method **createPlayer** throws a **NoDataSourceException** if it is unable to locate the specified media data source.

ANSWERS TO SELF-REVIEW EXERCISES

22.1 a) **Manager**. b) **MediaLocator**. c) **AudioSystem**, **MidiSystem**. d) **RealizeCompleteEvent**. e) **ProcessorModel**. f) *Configuring*, *Configured*, *Realizing*, *Realized*, *Prefetching*, *Prefetched*. g) **FileTypeDescriptor.QUICKTIME**. h) **DataSink**, **RTPManager**. i) **FormatControl**. j) **loop**, **Clip.LOOP_CONTINUOUSLY**. k) **Sequence**, events, message.

22.2 The answers to Self-Review Exercise 3.2 are as follows:
a) True.
b) False. A **DataSinkListener** handles **DataSinkEvent**s generated by a **DataSink**.
c) False. Objects that implement **Player** or **Processor** can play media.
d) False. Both a **Processor** and a **Player** can access media from capture devices.
e) False. A **Sequencer** plays MIDI sequences.
f) True.
g) False. Each **RTPManager** can stream only one track.
h) False. Method **createPlayer** throws a **NoPlayerException** if it is unable to locate the specified media data source.

EXERCISES

22.3 Wave audio clips are commonly used to play sounds that alert the user of a problem in a program. Typically, such sounds are accompanied by error-message dialogs. Modify the **DivideByZeroTest** example of Fig. 14.1 to play an error-message sound (in addition to displaying an error message dialog) if the user enters an invalid integer or attempts to divide by zero. Preload a compatible sound clip using a **Clip** line as demonstrated in Fig. 22.5. The **Clip** line needs to support only the format of the chosen sound clip. There should be a separate method that invokes the playback of the clip. When the program detects an exception, it should call this method to play the error message sound. After each clip playback, the program needs to rewind the clip by invoking **Clip**'s method ***setFramePosition*** with the frame position as the argument, so that the clip can replay from its beginning position.

22.4 Incorporate MIDI file playback capabilities, as demonstrated in class **MidiData** (Fig. 22.7), into the **ClipPlayer** demo. Class **ClipPlayer** should have separate methods for obtaining MIDI sequence data and for playing back the sequence with a sequencer.

22.5 The **SimplePlayer** demo (Fig. 22.7) demonstrated JMF's media playback (videos, capture media) capabilities using interface **Player**. Using the **SimplePlayer** demo as a guideline, develop a karaoke application in which one portion of the program plays a music/video file (preferably without lyrics) while another portion of the program simultaneously captures the user's voice. The program should start playback and capture as soon as it obtains the media. It is important that the program allows the user to control both the capture and music, so the control GUIs of each media should be displayed. When the media file finishes playing, the voice capture should cease and the program

should reset the music to the beginning. The program should close all **Player**-related resources when the user terminates the program.

22.6 Modify your solution to Exercise 3.5 by implementing the program using interface **Processor**. Create a **Processor** that is ready to display media with no format or output specifications. The voice capture should not end and the media should not rewind when the media finishes playing. Deallocate **Processor**-related resources when the user opens a new file or closes the program. All other program details remain the same as specified in Exercise 3.5.

22.7 Referring to the file saving process demonstrated in class **CapturePlayer** (Fig. 22.2), modify your solution to Exercise 22.6 by saving both audio streams to two separate QuickTime files. Specify the media tracks to be in ***AudioFormat.IMA4*** encoding. The program should display file saver dialogs for each audio file saver and a message when the saving completes or stops. There should be separate data writers for each audio stream. The program should close the data writers when there is no more data to process or when the user terminates the program. **DataSinkEvent** method ***getSourceDataSink*** is available to obtain the **DataSink** that is generating the **DataSinkEvent**. Use **MonitorControl**s to monitor both audio streams, so there is no need to display video or default user controls. **MonitorControl** method **setEnabled** is available to enable monitoring of the audio streams. Display one of the **MonitorControl**s in a dialog box. Make sure to close **Processor** resources when there is no more data from the media file or when the user opens another file or terminates the program.

22.8 Modify class **MidiSynthesizer** (Fig. 22.9) into an application where the user can play violin notes by pressing the computer keyboard keys. Use the virtual key code of the keys to specify the note number that the synthesizer should play. The violin's program number is 40. Use the first and ninth channel to sound the notes at the same time. The ninth channel may generate a different version of the violin notes.

SPECIAL SECTION: CHALLENGING MULTIMEDIA PROJECTS

The preceding exercises are keyed to the text and designed to test the reader's understanding of fundamental JMF and Java Sound concepts. This section includes a collection of advanced multimedia projects. The reader should find these problems challenging, yet entertaining. The problems vary considerably in difficulty. Some require an hour or two of program writing and implementation. Others are useful for lab assignments that might require two or three weeks of study and implementation. Some are challenging term projects. [*Note*: Solutions are not provided for these exercises.].

22.9 Modify the **ClipPlayer** (Fig. 22.5, Fig. 22.6) demo to provide a replay checkbox that allows the user to replay the sampled audio file.

22.10 Modify the **RTPServer** demo (Fig. 22.3) to enable transmission of the audio portions of media files to two clients. The application testing class should have twice the number of IP and port number inquiry dialog boxes. The program can check for audio formats by matching track control formats of the media to be instances of ***AudioFormat*** (class **AudioFormat**).

22.11 Many Web sites are able to play video clips. The **SimplePlayer** (Fig. 22.1) program can be an applet. Simplify the **SimplePlayer** program to an applet that plays a preloaded media clip on a web page. Insert this applet tag into your HTML file:

```
<applet code = AppletName.class width = # height = # >
   <param name = file value = "sample.mov" >
</applet>
```

22.12 Modify class **MidiRecord** (Fig. 22.8) and class **MidiData** (Fig. 22.7) to create a new application class that duplicates MIDI files by recording the sequence to a new file. Play the sequence

using **MidiData** and use its **Transmitter** to transmit MIDI information to the **Receiver** of **MidiRecord**.

22.13 Modify your solution to Exercise 22.6 to create a streaming karaoke application in which the application streams only the video portion of a music video and the sound stream is replaced by a voice capture stream. [Note: If the video format contains only one track for both audio and video, the application cannot choose to stream only the video portion of the track.]

22.14 Modify class **MidiData** (Fig. 22.7) to load all tracks of a MIDI file and revise class **MidiDemo** (Fig. 22.10) to enable the user to select the playback of each individual track displayed in a **JList** selector panel. Allow the user to replay the sequence forever.

22.15 Implement an MP3 player with a file list window using **Vector**s and a **JList**.

22.16 Modify class **MidiRecord** (Fig. 22.8) and class **MidiDemo** (Fig. 22.10) to allow the user to record MIDI to individual tracks stored in a **Vector**. Playback of the recorded MIDI should play all MIDI tracks simultaneously.

22.17 Currently the **MidiDemo** program (Section 22.7) records synthesized music with the first available instrument (i.e., Grand Piano). Modify class **MidiDemo** so that music will be recorded with a user-selected instrument, and allow the user to change the instrument during recording. Also allow the user to import their own sound banks. Make changes to classes **MidiSynthesizer**, **MidiData** and **MidiRecord** as needed. (Hint: The command parameter to change instrument is **ShortMessage.PROGRAM_CHANGE**)

22.18 Modify the **SimplePlayer** demo (Fig. 22.1) to support multiple media players. Present each media clip in its own **JInternalFrame**. The program needs to create separate **Player**s for each media clip and should register a **ControllerListener** for each player. **ControllerEvent** method ***getSourceController*** is available to obtain the controller generating the **ControllerEvent**. Implement the program using a dynamic data structure such as a **Vector** to store the multiple **Player**s.

22.19 Modify your solution to Exercise 3.7 to save both media streams to one file and play the combined stream. Use **Manager** method ***createMergingDataSource***, which receives an array of **DataSource** objects, to save both the capture stream and the music stream into one stream, whose content-type will be **MIXED**. The program should obtain the output **DataSource**s from the **Processor**s as the **DataSource** objects to be merged. The program must also obtain a duplicate **DataSource** (of the merged **DataSource**) for creating the **Player** for that **DataSource**. To do this, use **Manager** method ***createCloneableDataSource*** to create a ***Cloneable*** **DataSource** with the merged **DataSource** as the argument. Duplicate the **DataSource** for the player by invoking method ***createClone*** of interface **Cloneable** on the **DataSource** (similar to obtaining the **FormatControl**s of a **CaptureDevice DataSource** in the **CapturePlayer** demo (Fig. 22.2)).

22.20 A program can record MIDI without the use of transmitters and receivers by manually creating **MidiMessage**s, placing them in **MidiEvent**s, and adding these events to a **track**. In addition to the **MidiMessage** argument, a program must specify a time stamp to create the **MidiEvent**, expressed in *ticks* (i.e. milliseconds of long type), so the program must obtain the system's current time in milliseconds, which can be obtained from **System** method ***currentTimeMillis***. **Track** method **add** is available to add events to a track. Create an acoustics table (e.g. drums, cymbals, etc.) where the user can selected a sequence of instruments to play. Allow the user to save the recorded MIDI sequence to a file.

22.21 Create a peer-to-peer teleconferencing kit that enables users to talk to and hear each other. To listen to each other, each user must open an RTP session for the capture stream. A program can open an RTP stream with a **MediaLocator** specifying the RTP session address. Then, the program

can use the **MediaLocator** to create a **Player** for the RTP stream. The program can send the voice capture as demonstrated in the **RTPManager** demo (Fig. 22.3). To send the voice capture to more than two people, use **RTPManager**s for each separate session and call its **addTarget** method to add each recipient's session address as a destination of the capture stream. This is referred to as ***multicast-unicast*** sessions.

22.22 Using the "piano player" driver (Section 22.7.4 discusses the driver) from class **MidiDemo** (Fig. 22.10) and image animation functions from Chapter 18, write a program that displays a bouncing ball whose pinnacle height is specified by the note numbers (of a **ShortMessage** in a **MidiEvent**) of a loaded track in a MIDI file. The program should use the duration ticks of the **MidiEvent** as the duration of the bounce.

22.23 Most karaoke music videos are in MPEG format, for which JMF provides an ***MpegAudioControl*** interface to control the audio channels. For multilingual and karaoke MPEG videos, channel layers direct the main audio to one of two audio streams (e.g. english-dubbed audio stream) or both audio streams (e.g. both music and song channels turned on in karaoke videos). As an additional feature for MPEG videos to your solution to Exercise 3.6, obtain and display the control GUI component from a **MpegAudioControl**, if any, or display a customized radio button GUI selector to let the user select the channel layout of the MPEG audio. Interface **MpegAudioControl** provides method ***setChannelLayout*** to set the audio channel layout for MPEG videos, with the channel layout as the argument. (Refer to the use of **MonitorControl** in Fig. 22.2)

22.24 Create a multimedia-rich Tic-Tac-Toe game that plays sampled audio sounds when a player makes a valid move or makes an invalid move. Use a **Vector** to store preloaded **AudioInputStream**s representing each audio clip. Use a **Clip** line to play sounds in response to the user interactions with the game. Play continuous MIDI background music while the game is in progress. Use the JMF's interface **Player** to play a video when a player wins.

22.25 Java Sound's MIDI package can access MIDI software devices as well as hardware devices. If you have a MIDI keyboard that the computer can detect or one that can be plugged into a MIDI IN port of a sound card, Java Sound can access that keyboard. Use synthesizers, receivers, transmitters and sequencers to allow the user to record MIDI synthesized by the electronic keyboard. **MidiSystem** method ***getMidiDeviceInfo*** is available to obtain all detectable MIDI devices' information (array of ***MidiDevice.Info*** objects). Use **MidiSystem** method ***getMidiDevice*** with a **MidiDevice.Info** argument to obtain the specified MIDI device resource.

22.26 Enhance the **MidiDemo** program to allow for more configurations such as tempo, control and replay. **Sequencer**s can implement **MetaEventListener**s to handle **MetaMessage**s and **ControlEventListener**s to handle **ShortMessage.CONTROL_CHANGE** commands (see the MIDI specification for the type of changes and the various **MetaEvent**s). Interface **Sequencer** also provides many configuration and control methods that affect sequencer playback.

22.27 Enhance the **RTPServer** program (Fig. 22.3, Fig. 22.4) to a video distribution server where a live video feed from a video capture device (e.g., VFW TV card, digital cameras) is broadcast to everyone in the network. Use the IP address ending with **.255** (i.e. to create a **SessionAddress**) to broadcast to everyone in the network subnet. A server program should have access to stream transmission status, error controls and delay management. Package **javax.media.rtp** provides many interfaces to handle stream configurations and statistics. Package **javax.media.rtcp** allows the user to access RTP session reports. Package **javax.media.rtp.event** contains many events generated during an RTP session that can be used to perform RTP enhancements at those stages in the session. Package **javax.media.control** provides several control interfaces useful in RTP sessions.

22.28 Enhance the media player application solution to Exercise 3.18 by adding editing features to the program. First add a replay checkbox. Although a **Processor** is more suitable for control tasks than a **Player** is, one can also use both interfaces by creating a **Player** for the output **Data-**

`Source` from the **`Processor`**. Control features should include track formatting, frame control setting (interface ***`FrameRateControl`***), buffer control (interface ***`BufferControl`***), and quality control (interface ***`QualityControl`***). Include a program option that allows the user to save media clips given the settings of these controls. For capture devices, there is a ***`PortControl`*** interface available to control their ports of devices. These interfaces are in package **`javax.media.control`**. In package **`javax.media`**, there are other interfaces such as ***`Codec`*** and ***`Effect`*** that enable further rendering and processing of media to specific media formats. Allow the user to import new codecs. Also implement an editing feature which enables the user to extract certain portions of a media clip. (Hint: set the media position of a media clip and obtain the **`Processor`** output at the marked positions.)

22.29 Package **`javax.media.sound`** offers many audio system resources. Use this package to create a sound capture program that allows the users to save the capture stream in their desired formats, bit rates, frequencies and encodings.

22.30 Create a visualization studio that displays graphics bars that synchronize with sampled audio playback.

22.31 Extend MP3 playback support for class **`ClipPlayer`** (Fig. 22.5) using classes in package **`javax.media.sound.spi`**. The MP3 encoding process uses the Huffman algorithm.

22.32 *(Story Teller)* Record audio for a large number of nouns, verbs, articles, prepositions, etc. Then use random number generation to forms sentences and have your program speak the sentences.

22.33 *(Project: Multimedia Authoring System)* Develop a general-purpose multimedia authoring system. Your program should allow the user to form multimedia presentations consisting of text, audios, images, animations and eventually, videos. Your program lets the user weave together a presentation consisting of any of these multimedia elements that are selected from a catalog your program displays. Provide controls to allow the user to customize the presentation dynamically as the presentation is delivered.

22.34 *(Video Games)* Video games have become wildly popular. Develop your own Java video game program. Have a contest with your classmates to develop the best original video game.

22.35 *(Physics Demo: Bouncing Ball)* Develop an animated program that shows a bouncing ball. Give the ball a constant horizontal velocity. Allow the user to specify the coefficient of restitution, e.g., a coefficient of restitution of 75% means that after the ball bounces it returns to only 75% of its height before it was bounced. Your demo should take gravity into effect—this will cause the bouncing ball to trace a parabolic path. Track down a "boing" sound (like a spring bouncing) and play the sound every time the ball hits the ground.

22.36 *(Physics Demo: Kinetics)* If you have taken physics, implement a Java program that will demo concepts like energy, inertia, momentum, velocity, acceleration, friction, coefficient of restitution, gravity and others. Create visual effects and use audios for emphasis and realism.

22.37 *(Project: Flight Simulator)* Develop your own flight simulator Java program. This is a very challenging project. It is also an excellent candidate for a contest with your classmates.

22.38 *(Towers of Hanoi)* Write an animated version of the Towers of Hanoi problem we presented in Exercise 6.37. As each disk is lifted off a peg or slid onto a peg play a "whooshing" sound. As each disk lands on the pile play a "clunking" sound. Play some appropriate background music.

22.39 *(Tortoise and the Hare)* Develop a multimedia version of the Tortoise and Hare simulation we presented in Exercise 7.41. You might record an announcer's voice calling the race, "The contenders are at the starting line." "And they're off!" "The Hare pulls out in front." "The Tortoise is coming on strong." etc. As the race proceeds, play the appropriate recorded audios. Play sounds to simulate the animals' running, and don't forget the crowd cheering! Do an animation of the animals racing up the side of the slippery mountain.

22.40 *(Knight's Tour Walker)* Develop multimedia-based versions of the Knight's Tour programs you wrote in Exercises 7.22 and 7.23.

22.41 *(Pinball Machine)* Here's another contest problem. Develop a Java program that simulates a pinball machine of your own design. Have a contest with your classmates to develop the best original multimedia pinball machine. Use every possible multimedia trick you can think of to add "pizzazz" to your pinball game. Try to keep the game mechanisms close to those of real pinball games.

22.42 *(Roulette)* Study the rules for the game of roulette and implement a multimedia-based version of the game. Create an animated spinning roulette wheel. Use audio to simulate the sound of the ball jumping the various compartments that correspond to each of the numbers. Use an audio to simulate the sound of the ball falling into its final slot. While the roulette wheel is spinning, allow multiple players to place their bets. When the ball lands in its final slot, you should update the bank accounts of each of the players with the appropriate wins or losses.

22.43 *(Craps)* Simulate the complete game of craps. Use a graphical representation of a craps table. Allow multiple players to place their bets. Use an animation of the player who is rolling the dice and show the animated dice rolling eventually to a stop. Use audio to simulate some of the chatter around the craps table. After each roll, the system should update the bank accounts of each of the players depending on the bets they have made.

22.44 *(Morse Code)* Modify your solution to Exercise 10.26 to output the morse code using audio clips. Use two different audio clips for the dot and dash characters in Morse code.

Java Demos

A.1 Introduction[1]

In this appendix, we list some of the best Java demos we found on the Web. We began our journey at **`software.dev.earthweb.com/java`**. This site is an incredible Java resource and has some of the best Java demos including a huge compilation of games. The code ranges from basic to complex. Many of the authors of these games and other resources have provided source code. We hope you enjoy surfing these sites as much as we did.

A.2 The Sites

`softwaredev.earthweb.com/java`
Gamelan, a site owned by *EarthWeb*, has been a wonderful Java resource since the early days of Java. This site originally was a large Java repository where individuals traded ideas on Java and examples of Java programming. One of its early benefits was the volume of Java source code that was available to the many people learning Java. It is now an all-around Java resource with Java references, free Java downloads, areas where you can ask questions to Java experts, discussion groups on Java, a glossary of Java-related terminology, upcoming Java-related events, directories for specialized industry topics and hundreds of other Java resources.

`www.jars.com`
Another *EarthWeb* Web site is *JARS*—originally called the *Java Applet Rating Service*. The JARS site calls itself the "#1 Java Review Service." This site originally was a large Java repository for applets. It rated every applet registered at the site as top 1%, top 5% and top 25%, so you could immediately view the best applets on the Web. Early in the development of the Java language, having your applet rated here was a great way to demonstrate your Java programming abilities. JARS is now another all-around resource for Java programmers.

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1. There are many Java-related Web sites that cover more advanced Java topics such as servlets, JavaServer Pages (JSP), Enterprise Java Beans (EJB), database, Java 2 Enterprise Edition (J2EE), Java 2 Micro Edition (J2ME), Security, XML and many more. These sites are provided in our companion book, *Advanced Java 2 Platform How to Program* (ISBN# 0-13-089560-1).

www.javashareware.com
Java Shareware contains hundreds of Java applications, applets, classes and other Java resources. The site includes a large number of links to other Java developer Web sites.

javaboutique.internet.com
Java Boutique is a great resource for any Java programmer. The site offers applets, applications, forums, tutorials, reviews, glossaries and more.

www.thejmaker.com
The J Maker has numerous live Java demos, including games, menus and animated visual effects. Many of the programs on this site are acclaimed worldwide and some have won awards.

www.demicron.com/gallery/photoalbum2/index.shtml
The PhotoAlbum II has some of the coolest effects we have found on the Web. The effects include a liquid effect, folding an image into a paper airplane and others.

www.blaupunkt.de/simulations/svdef_en.html
The *Sevilla RDM 168* is a simulation, built with Java, of a car Radio and CD player. You can tune into a variety of on-line radio stations or CDs, adjust the volume, clock settings and more.

www.frontiernet.net/~imaging/play_a_piano.html
Play A Piano is a Java applet that allows you to play the piano or watch the sound waves and listen as the piano plays itself.

www.gamesdomain.co.uk/GamesArena/goldmine
Goldmine is a fun game using simple animation.

www.javaonthebrain.com
This site offers many new and original Java games for the Web. Source code for many of the programs is provided.

www.javagamepark.com
If you are looking for games, the *Java Game Park* site has loads of them. All of the games are written in Java. The source code is provided in some cases.

teamball.sdsu.edu/~boyns/java/
This site has interesting games written in Java and includes source code for many of them.

www.cruzio.com/~sabweb/arcade/index.html
SABames Arcade is another source for Java video games. Source code is provided for many of the games. Don't miss the SabBowl bowling game.

dogfeathers.com/java/hyprcube.html
Stereoscopic Animated Hypercube. If you happen to possess the old red and blue 3D glasses, check this site out. The programmer was able to create a 3D image using Java. It isn't really a complicated image, just some cubes, however the idea that you can create images that will jump off your screen is a great concept!

www.npac.syr.edu/projects/vishuman/VisibleHuman.html
This site has won various awards. You can look at cross sections of the human body.

www-groups.dcs.st-and.ac.uk/~history/Java/
Famous Curves Applet Index. Provides graphs of complex curves. Allows the user to alter the parameters to the equations that calculate the curves.

Java Resources

B.1 Resources[1]

`java.sun.com`
The *Sun Microsystems, Inc. Java Web site* is an essential stop when searching the Web for Java information. Go to this site to download the Java 2 Software Development Kit. This site offers news, information, on-line support, code samples and more.

`java.sun.com/docs/codeconv/html/CodeConvTOC.doc.html`
This site reviews the *Sun Microsystems, Inc.* code conventions for the Java programming language.

`www.softwaredev.earthweb.com`
This site provides a wide variety of information on Java and other Internet-related topics. The Java directory page contains links to thousands of Java applets and other Java resources.

`softwaredev.earthweb.com/java`
The *Gamelan* site has been a wonderful Java resource since the early days of Java. This site originally was a large Java repository where individuals traded ideas on Java and examples of Java programming. One of its early benefits was the volume of Java source code that was available to the many people learning Java. It is now an all-around Java resource with Java references, free Java downloads, areas where you can ask questions of Java experts, discussion groups on Java, a glossary of Java terminology, upcoming Java events, directories for specialized industry topics and hundreds of other Java resources.

`www.jars.com`
Another *Earthweb.com* Web site is *JARS*—originally called the *Java Applet Rating Service*. The JARS site calls itself the "#1 Java Review Service." This site originated as a large Java repository for applets. Its benefit was that it rated every applet registered at the site as top 1%, top 5% and top 25%, so you could immediately view the best applets on the Web. Early in the development of the Java language, having your applet rated here was a great way to demonstrate your Java programming abilities. JARS is now another all-around resource for Java programmers.

1. There are many Java-related Web sites that cover more advanced Java topics such as servlets, JavaServer Pages (JSP), Enterprise Java Beans (EJB), database, Java 2 Enterprise Edition (J2EE), Java 2 Micro Edition (J2ME), Security, XML and many more. These sites are provided in our companion book, *Advanced Java 2 Platform How to Program* (ISBN# 0-13-089560-1).

developer.java.sun.com/developer
On the Sun Microsystems Java Web site, visit the *Java Developer Connection*. The site includes technical support, discussion forums, on-line training courses, technical articles, resources, announcements of new Java features, early access to new Java technologies and links to other important Java Web sites. Even though the site is free, you must register to use it.

www.acme.com/java
This page has several animated Java applets with the source code provided. This site is an excellent resource for information on Java. The page provides software, notes and a list of hyperlinks to other resources. Under software you will find animated applets, utility classes and applications.

www.javaworld.com/index.html
The JavaWorld online magazine provides a collection of Java articles, tips, news and discussions. A questions area of this site addresses both general and specific problems programmers face.

www.nikos.com/javatoys
The *Java Toys* Web site includes links to the latest Java news, Java User Groups (JUGs), FAQs, tools, Java-related mailing lists, books and white papers.

www.java-zone.com
The *Development Exchange Java Zone* site includes Java discussion groups, an "ask the Java Pro" section and some recent Java news.

www.ibiblio.org/javafaq
This site provides the latest Java news. It also has some helpful Java resources including a Java FAQ List, a tutorial called Brewing Java, Java User Groups, Java Links, the Java Book List, Java Trade Shows, Java Training and Exercises.

dir.yahoo.com/Computers_and_Internet/Programming_Languages/Java
Yahoo, a popular World Wide Web search engine, provides a complete Java resource. You can initiate a search using key words or explore the categories listed at the site including games, contests, events, tutorials and documentation, mailing lists, security and more.

www-106.ibm.com/developerworks/java
The *IBM Developers Java Technology Zone* site lists the latest news, tools, code, case studies and events related to IBM and Java.

B.2 Products

java.sun.com/products
Download the Java 2 SDK and other Java products from the *Sun Microsystems Java Products page*.

www.sun.com/forte/ffj/index.cgi
The *NetBeans* IDE is a customizable, platform independent, visual programming development environment.

www.borland.com/jbuilder
The *Borland JBuilder* IDE home page has news, product information and customer support.

www.towerj.com
At this site you will find information on how to enhance the performance of server-side Java applications along with free evaluation copies of native Java compilers.

www.symantec.com/domain/cafe
Visit the *Symantec* site for information on their *Visual Café Integrated Development Environment*.

www-4.ibm.com/software/ad/vajava
Download and read more about the IBM Visual Age for Java development environment.

www.metrowerks.com
The *Metrowerks CodeWarrior* IDE supports a few programming languages, including Java.

B.3 FAQs

www.ibiblio.org/javafaq/javafaq.html
This is a comprehensive resource for both Java language basics and more advanced topics in Java Programming. *Section 6: Language Issues* and *Section 11: Common Errors and Problems* may be particularly useful, as they clarify situations that often are not explained well.

www.afu.com/javafaq.html
This is another FAQ which covers a fairly broad slice of topics in Java. This includes some good code samples and hints for getting projects to compile and run.
www.nikos.com/javatoys/faqs.html
The *Java Toys* Web site includes links to FAQs on a broad range of Java-related topics.

www.jguru.com/faq/index.jsp
This is a thorough compilation of FAQs on Java and related subjects. Questions can be read in order or searched for by subject.

B.4 Tutorials

Several tutorials are on the sites listed in the Resources section.

java.sun.com/docs/books/tutorial/
The *Java Tutorial Site* has a number of tutorials, including sections on JavaBeans, JDBC, RMI, Servlets, Collections and Java Native Interface.

www.ibiblio.org/javafaq/
This site provides the latest Java news. It also has some helpful Java resources including the Java FAQ List, a tutorial called Brewing Java, Java User Groups, Java Links, the Java Book List, Java Conferences, Java Course Notes and Java Seminar Slides.

B.5 Magazines

www.javaworld.com
The *JavaWorld* on-line magazine is an excellent resource for current Java information. You will find news clips, conference information and links to Java-related Web sites.

www.sys-con.com/java
Catch up with the latest Java news at the *Java Developer's Journal* site. This magazine is one of the premier resources for Java news.

www.javareport.com
The *Java Report* is a great resource for Java developers. You will find the latest industry news, sample code, event listings, products and jobs.

www.javapro.com
The *JAVAPro* is an excellent Java developer resource with up-to-the-minute technical articles.

B.6 Java Applets

java.sun.com/applets/index.html
This page contains a variety of Java applet resources, including free applets you can use on your own Web site, the demonstration applets from the J2SDK and a variety of other applets. There is a section entitled "Applets at Work" where you can read about applets in industry.

developer.java.sun.com/developer/
On the Sun Microsystems Java Web site, visit the *Java Developer Connection*. This free site has close to one million members. The site includes technical support, discussion forums, on-line training courses, technical articles, resources, announcements of new Java features, early access to new Java technologies, and links to other important Java Web sites.

www.gamelan.com
Gamelan, a site owned by *EarthWeb*, has been a wonderful Java resource since the early days of Java. This site originally was a large Java repository where individuals traded ideas on Java and examples of Java programming. One of its early benefits was the volume of Java source code that was available to the many people learning Java. It is now an all-around Java resource with Java references, free Java downloads, areas where you can ask questions to Java experts, discussion groups on Java, a glossary of Java-related terminology, upcoming Java-related events, directories for specialized industry topics and hundreds of other Java resources.

www.jars.com
Another *EarthWeb* Web site is *JARS*—originally called the *Java Applet Rating Service*. The JARS site calls itself the "#1 Java Review Service." This site originally was a large Java repository for applets. Its benefit was that it rated every applet registered at the site as top 1%, top 5% and top 25%, so you could immediately view the best applets on the Web. Early in the development of the Java language, having your applet rated here was a great way to demonstrate your Java programming abilities. JARS is now another all-around resource for Java programmers.

B.7 Multimedia

java.sun.com/products/java-media/jmf
This is the *Java Media Framework home page* on the Java Web site. Here you can download the latest Sun implementation of the JMF (see Chapter 22). The site also contains the documentation for the JMF.

www.nasa.gov/gallery/index.html
The *NASA multimedia gallery* contains a wide variety of images, audio clips and video clips that you can download and use to test your Java multimedia programs.

sunsite.sut.ac.jp/multimed
The *Sunsite Japan Multimedia Collection* also provides a wide variety of images, audio clips and video clips that you can download for educational purposes.

www.anbg.gov.au/anbg/index.html
The *Australian National Botanic Gardens* Web site provides links to the audio clips of many animal sounds.

java.sun.com/products/java-media/jmf/index.html
This site provides an HTML-based on-line guide to the Java Media Framework API.

B.8 Newsgroups

Newsgroups are forums on the Internet in which people can post questions, responses, hints and clarifications for other users. Newsgroups can be a valuable resource to anyone learning Java or anyone with questions on specific Java topics. When posting your own questions to a newsgroup, provide specific details of the problem you are trying to solve (such as a problem with a program you are writing). This will enable other people reading the newsgroup to understand your posting and (hopefully) provide a response to you. Be sure to specify a subject heading that clearly states your problem. If you are responding to other people's

questions, verify your response before posting it to ensure that the response is correct. Newsgroups should not be used to promote products or services, nor should contact information (such as email addresses for other newsgroup users) be used for unrelated purposes. These are generally not forums for chatting, so posts should be courteous and to the point.

Normally, newsgroup reader software is required for you to interact with a newsgroup. Such software is provided as part of Netscape Navigator and Microsoft Outlook Express, and there are many other newsgroup software programs available. You also can access newsgroups through the Web. If you do not use newsgroups already, try the *Google* site

```
groups.google.com
```

Type the name of the group you would like to view (you can also search for newsgroups) and you will be presented with a list of that newsgroup's current topics and questions. Listed below are some Java newsgroups that you may find useful.

news:comp.lang.java.advocacy
This group is an active center of discussion for current Java culture, including the merits of different programming languages.

news:comp.lang.java.announce
This group provides announcements on major additions to Java, new class libraries and conferences.

news:comp.lang.java.api
This groups contains questions about bugs, compile errors, Java specifications and which classes are most appropriate for different situations.

news:comp.lang.java.gui
This group responds to problems encountered working with Java graphical user interfaces. If you are having trouble with a particular component, layout or event, this may be a good place to start.

news:comp.lang.java.help
This group is particularly active. It addresses many language and environment issues. Questions include requests for classes or algorithms that solve a specific problem.

news:comp.lang.java.machine
For people interested in the inner workings of Java, this group focuses on the Java Virtual Machine.

news:comp.lang.java.misc
This group contains everything from job postings to questions about the Java documentation and is mainly for questions that do not fit into other Java newsgroup categories.

news:comp.lang.java.programmer
This group is another extremely active forum that addresses a range of questions. Posts tend to be largely project-oriented and concerned with overall program style and structure.

news:comp.lang.java.softwaretools
This newsgroup is centered around Java software products, their uses, their faults and possible modifications. Some questions about writing effective software are also included here.

news:comp.lang.java.tech
This is a new group devoted to the technical aspects of Java and its inner workings.

Operator Precedence Chart

Operators are shown in decreasing order of precedence from top to bottom.

Operator	Type	Associativity
`()`	parentheses	left to right
`[]`	array subscript	
`.`	member selection	
`++`	unary postincrement	right to left
`--`	unary postdecrement	
`++`	unary preincrement	right to left
`--`	unary predecrement	
`+`	unary plus	
`-`	unary minus	
`!`	unary logical negation	
`~`	unary bitwise complement	
`(` *type* `)`	unary cast	
`*`	multiplication	left to right
`/`	division	
`%`	modulus	
`+`	addition	left to right
`-`	subtraction	
`<<`	bitwise left shift	left to right
`>>`	bitwise right shift with sign extension	
`>>>`	bitwise right shift with zero extension	

Fig. C.1 Operator precedence chart (part 1 of 2).

Operator	Type	Associativity
`<`	relational less than	left to right
`<=`	relational less than or equal to	
`>`	relational greater than	
`>=`	relational greater than or equal to	
`instanceof`	type comparison	
`==`	relational is equal to	left to right
`!=`	relational is not equal to	
`&`	bitwise AND	left to right
`^`	bitwise exclusive OR boolean logical exclusive OR	left to right
`|`	bitwise inclusive OR boolean logical inclusive OR	left to right
`&&`	logical AND	left to right
`||`	logical OR	left to right
`?:`	ternary conditional	right to left
`=`	assignment	right to left
`+=`	addition assignment	
`-=`	subtraction assignment	
`*=`	multiplication assignment	
`/=`	division assignment	
`%=`	modulus assignment	
`&=`	bitwise AND assignment	
`^=`	bitwise exclusive OR assignment	
`|=`	bitwise inclusive OR assignment	
`<<=`	bitwise left shift assignment	
`>>=`	bitwise right shift with sign extension assignment	
`>>>=`	bitwise right shift with zero extension assignment	

Fig. C.1 Operator precedence chart (part 2 of 2).

ASCII Character Set

	0	1	2	3	4	5	6	7	8	9
0	nul	soh	stx	etx	eot	enq	ack	bel	bs	ht
1	nl	vt	ff	cr	so	si	dle	dc1	dc2	dc3
2	dc4	nak	syn	etb	can	em	sub	esc	fs	gs
3	rs	us	sp	!	"	#	$	%	&	‘
4	(	)	*	+	,	-	.	/	0	1
5	2	3	4	5	6	7	8	9	:	;
6	<	=	>	?	@	A	B	C	D	E
7	F	G	H	I	J	K	L	M	N	O
8	P	Q	R	S	T	U	V	W	X	Y
9	Z	[	\	]	^	_	’	a	b	c
10	d	e	f	g	h	i	j	k	l	m
11	n	o	p	q	r	s	t	u	v	w
12	x	y	z	{	|	}	~	del		

Fig. D.1 ASCII character set.

The digits at the left of the table are the left digits of the decimal equivalent (0-127) of the character code, and the digits at the top of the table are the right digits of the character code. For example, the character code for “F” is 70, and the character code for “&” is 38.

Most users of this book are interested in the ASCII character set used to represent English characters on many computers. The ASCII character set is a subset of the Unicode character set used by Java to represent characters from most of the world’s languages. For more information on the Unicode character set, see Appendix K.

E

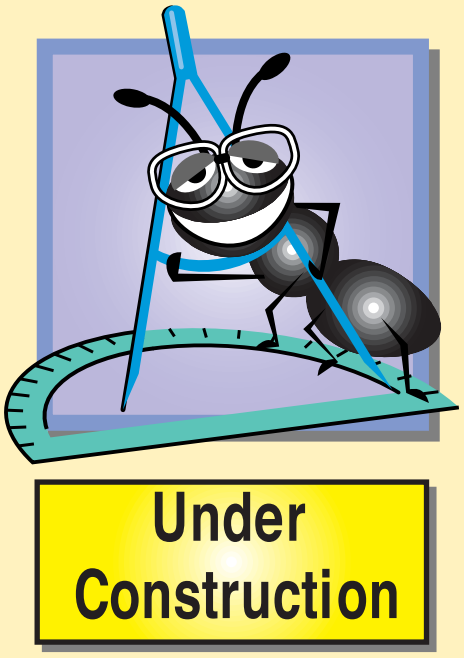
Number Systems (on CD)

Objectives

- To understand basic number systems concepts such as base, positional value, and symbol value.
- To understand how to work with numbers represented in the binary, octal, and hexadecimal number systems
- To be able to abbreviate binary numbers as octal numbers or hexadecimal numbers.
- To be able to convert octal numbers and hexadecimal numbers to binary numbers.
- To be able to covert back and forth between decimal numbers and their binary, octal, and hexadecimal equivalents.
- To understand binary arithmetic, and how negative binary numbers are represented using two's complement notation.

Here are only numbers ratified.
William Shakespeare

Nature has some sort of arithmetic-geometrical coordinate system, because nature has all kinds of models. What we experience of nature is in models, and all of nature's models are so beautiful.
It struck me that nature's system must be a real beauty, because in chemistry we find that the associations are always in beautiful whole numbers—there are no fractions.
Richard Buckminster Fuller



Outline

E.1 Introduction
E.2 Abbreviating Binary Numbers as Octal Numbers and Hexadecimal Numbers
E.3 Converting Octal Numbers and Hexadecimal Numbers to Binary Numbers
E.4 Converting from Binary, Octal, or Hexadecimal to Decimal
E.5 Converting from Decimal to Binary, Octal, or Hexadecimal
E.6 Negative Binary Numbers: Two's Complement Notation

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

E.1 Introduction

In this appendix, we introduce the key number systems that Java programmers use, especially when they are working on software projects that require close interaction with "machine-level" hardware. Projects like this include operating systems, computer networking software, compilers, database systems, and applications requiring high performance.

When we write an integer such as 227 or -63 in a Java program, the number is assumed to be in the decimal (base 10) number system. The digits in the decimal number system are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. The lowest digit is 0 and the highest digit is 9—one less than the base of 10. Internally, computers use the binary (base 2) number system. The binary number system has only two digits, namely 0 and 1. Its lowest digit is 0 and its highest digit is 1—one less than the base of 2.

As we will see, binary numbers tend to be much longer than their decimal equivalents. Programmers who work in assembly languages and in high-level languages like Java that enable programmers to reach down to the "machine level," find it cumbersome to work with binary numbers. So two other number systems the octal number system (base 8) and the hexadecimal number system (base 16)—are popular primarily because they make it convenient to abbreviate binary numbers.

In the octal number system, the digits range from 0 to 7. Because both the binary number system and the octal number system have fewer digits than the decimal number system, their digits are the same as the corresponding digits in decimal.

The hexadecimal number system poses a problem because it requires sixteen digits—a lowest digit of 0 and a highest digit with a value equivalent to decimal 15 (one less than the base of 16). By convention, we use the letters A through F to represent the hexadecimal digits corresponding to decimal values 10 through 15. Thus in hexadecimal we can have numbers like 876 consisting solely of decimal-like digits, numbers like 8A55F consisting of digits and letters, and numbers like FFE consisting solely of letters. Occasionally, a hexadecimal number spells a common word such as FACE or FEED—this can appear strange to programmers accustomed to working with numbers.

Each of these number systems uses positional notation—each position in which a digit is written has a different positional value. For example, in the decimal number 937 (the 9, the 3, and the 7 are referred to as symbol values), we say that the 7 is written in the ones position, the 3 is written in the tens position, and the 9 is written in the hundreds position.

Notice that each of these positions is a power of the base (base 10), and that these powers begin at 0 and increase by 1 as we move left in the number (Fig. E.3).

Binary digit	Octal digit	Decimal digit	Hexadecimal digit
0	0	0	0
1	1	1	1
	2	2	2
	3	3	3
	4	4	4
	5	5	5
	6	6	6
	7	7	7
		8	8
		9	9
			A (decimal value of 10)
			B (decimal value of 11)
			C (decimal value of 12)
			D (decimal value of 13)
			E (decimal value of 14)
			F (decimal value of 15)

Fig. E.1 Digits of the binary, octal, decimal and hexadecimal number systems.

Attribute	Binary	Octal	Decimal	Hexadecimal
Base	2	8	10	16
Lowest digit	0	0	0	0
Highest digit	1	7	9	F

Fig. E.2 Comparing the binary, octal, decimal and hexadecimal number systems.

Positional values in the decimal number system			
Decimal digit	9	3	7
Position name	Hundreds	Tens	Ones
Positional value	100	10	1
Positional value as a power of the base (10)	10^2	10^1	10^0

Fig. E.3 Positional values in the decimal number system.

For longer decimal numbers, the next positions to the left would be the thousands position (10 to the 3rd power), the ten-thousands position (10 to the 4th power), the hundred-thousands position (10 to the 5th power), the millions position (10 to the 6th power), the ten-millions position (10 to the 7th power), and so on.

In the binary number 101, we say that the rightmost 1 is written in the ones position, the 0 is written in the twos position, and the leftmost 1 is written in the fours position. Notice that each of these positions is a power of the base (base 2), and that these powers begin at 0 and increase by 1 as we move left in the number (Fig E.4).

For longer binary numbers, the next positions to the left would be the eights position (2 to the 3rd power), the sixteens position (2 to the 4th power), the thirty-twos position (2 to the 5th power), the sixty-fours position (2 to the 6th power), and so on.

In the octal number 425, we say that the 5 is written in the ones position, the 2 is written in the eights position, and the 4 is written in the sixty-fours position. Notice that each of these positions is a power of the base (base 8), and that these powers begin at 0 and increase by 1 as we move left in the number (Fig. E.5).

For longer octal numbers, the next positions to the left would be the five-hundred-and-twelves position (8 to the 3rd power), the four-thousand-and-ninety-sixes position (8 to the 4th power), the thirty-two-thousand-seven-hundred-and-sixty eights position (8 to the 5th power), and so on.

In the hexadecimal number 3DA, we say that the A is written in the ones position, the D is written in the sixteens position, and the 3 is written in the two-hundred-and-fifty-sixes position. Notice that each of these positions is a power of the base (base 16), and that these powers begin at 0 and increase by 1 as we move left in the number (Fig. E.6).

Positional values in the binary number system

Binary digit	`1`	`0`	`1`
Position name	Fours	Twos	Ones
Positional value	`4`	`2`	`1`
Positional value as a power of the base (2)	2^2	2^1	2^0

Fig. E.4 Positional values in the binary number system.

Positional values in the octal number system

Decimal digit	`4`	`2`	`5`
Position name	Sixty-fours	Eights	Ones
Positional value	`64`	`8`	`1`
Positional value as a power of the base (8)	8^2	8^1	8^0

Fig. E.5 Positional values in the octal number system.

Positional values in the hexadecimal number system			
Decimal digit	`3`	`D`	`A`
Position name	Two-hundred-and-fifty-sixes	Sixteens	Ones
Positional value	`256`	`16`	`1`
Positional value as a power of the base (16)	16^2	16^1	16^0

Fig. E.6 Positional values in the hexadecimal number system.

For longer hexadecimal numbers, the next positions to the left would be the four-thousand-and-ninety-sixes position (16 to the 3rd power), the sixty-five-thousand-five-hundred-and-thirty-six position (16 to the 4th power), and so on.

E.2 Abbreviating Binary Numbers as Octal Numbers and Hexadecimal Numbers

The main use for octal and hexadecimal numbers in computing is for abbreviating lengthy binary representations. Figure E.7 highlights the fact that lengthy binary numbers can be expressed concisely in number systems with higher bases than the binary number system.

Decimal number	Binary{ representation	Octal representation	Hexadecimal representation
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
4	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F
16	10000	20	10

Fig. E.7 Decimal, binary, octal, and hexadecimal equivalents.

A particularly important relationship that both the octal number system and the hexadecimal number system have to the binary system is that the bases of octal and hexadecimal (8 and 16 respectively) are powers of the base of the binary number system (base 2). Consider the following 12-digit binary number and its octal and hexadecimal equivalents. See if you can determine how this relationship makes it convenient to abbreviate binary numbers in octal or hexadecimal. The answer follows the numbers.

Binary Number	Octal equivalent	Hexadecimal equivalent
100011010001	**4321**	**8D1**

To see how the binary number converts easily to octal, simply break the 12-digit binary number into groups of three consecutive bits each, and write those groups over the corresponding digits of the octal number as follows

```
100    011    010    001
4      3      2      1
```

Notice that the octal digit you have written under each group of thee bits corresponds precisely to the octal equivalent of that 3-digit binary number as shown in Fig. E.7.

The same kind of relationship may be observed in converting numbers from binary to hexadecimal. In particular, break the 12-digit binary number into groups of four consecutive bits each and write those groups over the corresponding digits of the hexadecimal number as follows

```
1000   1101   0001
8      D      1
```

Notice that the hexadecimal digit you wrote under each group of four bits corresponds precisely to the hexadecimal equivalent of that 4-digit binary number as shown in Fig. E.7.

E.3 Converting Octal Numbers and Hexadecimal Numbers to Binary Numbers

In the previous section, we saw how to convert binary numbers to their octal and hexadecimal equivalents by forming groups of binary digits and simply rewriting these groups as their equivalent octal digit values or hexadecimal digit values. This process may be used in reverse to produce the binary equivalent of a given octal or hexadecimal number.

For example, the octal number 653 is converted to binary simply by writing the 6 as its 3-digit binary equivalent 110, the 5 as its 3-digit binary equivalent 101, and the 3 as its 3-digit binary equivalent 011 to form the 9-digit binary number 110101011.

The hexadecimal number FAD5 is converted to binary simply by writing the F as its 4-digit binary equivalent 1111, the A as its 4-digit binary equivalent 1010, the D as its 4-digit binary equivalent 1101, and the 5 as its 4-digit binary equivalent 0101 to form the 16-digit 1111101011010101.

E.4 Converting from Binary, Octal, or Hexadecimal to Decimal

Because we are accustomed to working in decimal, it is often convenient to convert a binary, octal, or hexadecimal number to decimal to get a sense of what the number is “really” worth. Our diagrams in Section E.1 express the positional values in decimal. To convert a number to decimal from another base, multiply the decimal equivalent of each digit by its

positional value, and sum these products. For example, the binary number 110101 is converted to decimal 53 as shown in Fig. E.8.

To convert octal 7614 to decimal 3980, we use the same technique, this time using appropriate octal positional values as shown in Fig. E.9.

To convert hexadecimal AD3B to decimal 44347, we use the same technique, this time using appropriate hexadecimal positional values as shown in Fig. E.10.

E.5 Converting from Decimal to Binary, Octal, or Hexadecimal

The conversions of the previous section follow naturally from the positional notation conventions. Converting from decimal to binary, octal, or hexadecimal also follows these conventions.

Suppose we wish to convert decimal 57 to binary. We begin by writing the positional values of the columns right to left until we reach a column whose positional value is greater than the decimal number. We do not need that column, so we discard it. Thus, we first write:

Converting a binary number to decimal

Positional values:	32	16	8	4	2	1
Symbol values:	1	1	0	1	0	1
Products:	1*32=32	1*16=16	0*8=0	1*4=4	0*2=0	1*1=1
Sum:	= 32 + 16 + 0 + 4 + 0 + 1 = 53					

Fig. E.8 Converting a binary number to decimal.

Converting an octal number to decimal

Positional values:	512	64	8	1
Symbol values:	7	6	1	4
Products	7*512=3584	6*64=384	1*8=8	4*1=4
Sum:	= 3584 + 384 + 8 + 4 = 3980			

Fig. E.9 Converting an octal number to decimal.

Converting a hexadecimal number to decimal

Positional values:	4096	256	16	1
Symbol values:	A	D	3	B
Products	A*4096=40960	D*256=3328	3*16=48	B*1=11
Sum:	= 40960 + 3328 + 48 + 11 = 44347			

Fig. E.10 Converting a hexadecimal number to decimal.

```
Positional values:  64   32   16   8    4    2    1
```

Then we discard the column with positional value 64 leaving:

```
Positional values:  32   16   8    4    2    1
```

Next we work from the leftmost column to the right. We divide 32 into 57 and observe that there is one 32 in 57 with a remainder of 25, so we write 1 in the 32 column. We divide 16 into 25 and observe that there is one 16 in 25 with a remainder of 9 and write 1 in the 16 column. We divide 8 into 9 and observe that there is one 8 in 9 with a remainder of 1. The next two columns each produce quotients of zero when their positional values are divided into 1 so we write 0s in the 4 and 2 columns. Finally, 1 into 1 is 1 so we write 1 in the 1 column. This yields:

```
Positional values:  32   16   8    4    2    1
Symbol values:      1    1    1    0    0    1
```

and thus decimal 57 is equivalent to binary 111001.

To convert decimal 103 to octal, we begin by writing the positional values of the columns until we reach a column whose positional value is greater than the decimal number. We do not need that column, so we discard it. Thus, we first write:

```
Positional values:  512  64   8    1
```

Then we discard the column with positional value 512, yielding:

```
Positional values:  64   8    1
```

Next we work from the leftmost column to the right. We divide 64 into 103 and observe that there is one 64 in 103 with a remainder of 39, so we write 1 in the 64 column. We divide 8 into 39 and observe that there are four 8s in 39 with a remainder of 7 and write 4 in the 8 column. Finally, we divide 1 into 7 and observe that there are seven 1s in 7 with no remainder so we write 7 in the 1 column. This yields:

```
Positional values:  64   8    1
Symbol values:      1    4    7
```

and thus decimal 103 is equivalent to octal 147.

To convert decimal 375 to hexadecimal, we begin by writing the positional values of the columns until we reach a column whose positional value is greater than the decimal number. We do not need that column, so we discard it. Thus, we first write

```
Positional values:  4096 256  16   1
```

Then we discard the column with positional value 4096, yielding:

```
Positional values:  256  16   1
```

Next we work from the leftmost column to the right. We divide 256 into 375 and observe that there is one 256 in 375 with a remainder of 119, so we write 1 in the 256 column. We divide 16 into 119 and observe that there are seven 16s in 119 with a remainder of 7 and write 7 in the 16 column. Finally, we divide 1 into 7 and observe that there are seven 1s in 7 with no remainder so we write 7 in the 1 column. This yields:

```
Positional values:      256  16   1
Symbol values:          1    7    7
```

and thus decimal 375 is equivalent to hexadecimal 177.

E.6 Negative Binary Numbers: Two's Complement Notation

The discussion in this appendix has been focussed on positive numbers. In this section, we explain how computers represent negative numbers using *two's complement notation*. First we explain how the two's complement of a binary number is formed, and then we show why it represents the negative value of the given binary number.

Consider a machine with 32-bit integers. Suppose

```
int value = 13;
```

The 32-bit representation of **value** is

```
00000000 00000000 00000000 00001101
```

To form the negative of **value** we first form its *one's complement* by applying Java's bitwise complement operator (**~**):

```
onesComplementOfValue = ~value;
```

Internally, **~value** is now **value** with each of its bits reversed—ones become zeros and zeros become ones as follows:

```
value:
00000000 00000000 00000000 00001101

~value (i.e., value's ones complement):
11111111 11111111 11111111 11110010
```

To form the two's complement of **value** we simply add one to **value**'s one's complement. Thus

```
Two's complement of value:
11111111 11111111 11111111 11110011
```

Now if this is in fact equal to -13, we should be able to add it to binary 13 and obtain a result of 0. Let us try this:

```
 00000000 00000000 00000000 00001101
+11111111 11111111 11111111 11110011
-----------------------------------
 00000000 00000000 00000000 00000000
```

The carry bit coming out of the leftmost column is discarded and we indeed get zero as a result. If we add the one's complement of a number to the number, the result would be all 1s. The key to getting a result of all zeros is that the twos complement is 1 more than the one's complement. The addition of 1 causes each column to add to 0 with a carry of 1. The carry keeps moving leftward until it is discarded from the leftmost bit, and hence the resulting number is all zeros.

Computers actually perform a subtraction such as

```
x = a - value;
```

by adding the two's complement of **value** to **a** as follows:

```
x = a + (~value + 1);
```

Suppose **a** is 27 and **value** is 13 as before. If the two's complement of **value** is actually the negative of **value**, then adding the two's complement of value to a should produce the result 14. Let us try this:

```
a (i.e., 27)          00000000 00000000 00000000 00011011
+(~value + 1)        +11111111 11111111 11111111 11110011
                     -----------------------------------
                      00000000 00000000 00000000 00001110
```

which is indeed equal to 14.

SUMMARY

- When we write an integer such as 19 or 227 or -63 in a Java program, the number is automatically assumed to be in the decimal (base 10) number system. The digits in the decimal number system are 0, 1, 2, 3, 4, 5, 6, 7, 8, and 9. The lowest digit is 0 and the highest digit is 9—one less than the base of 10.
- Internally, computers use the binary (base 2) number system. The binary number system has only two digits, namely 0 and 1. Its lowest digit is 0 and its highest digit is 1—one less than the base of 2.
- The octal number system (base 8) and the hexadecimal number system (base 16) are popular primarily because they make it convenient to abbreviate binary numbers.
- The digits of the octal number system range from 0 to 7.
- The hexadecimal number system poses a problem because it requires sixteen digits—a lowest digit of 0 and a highest digit with a value equivalent to decimal 15 (one less than the base of 16). By convention, we use the letters A through F to represent the hexadecimal digits corresponding to decimal values 10 through 15.
- Each number system uses positional notation—each position in which a digit is written has a different positional value.
- A particularly important relationship that both the octal number system and the hexadecimal number system have to the binary system is that the bases of octal and hexadecimal (8 and 16 respectively) are powers of the base of the binary number system (base 2).
- To convert an octal number to a binary number, simply replace each octal digit with its three-digit binary equivalent.
- To convert a hexadecimal number to a binary number, simply replace each hexadecimal digit with its four-digit binary equivalent.
- Because we are accustomed to working in decimal, it is convenient to convert a binary, octal or hexadecimal number to decimal to get a sense of the number's "real" worth.
- To convert a number to decimal from another base, multiply the decimal equivalent of each digit by its positional value, and sum these products.
- Computers represent negative numbers using two's complement notation.
- To form the negative of a value in binary, first form its one's complement by applying Java's bitwise complement operator (**~**). This reverses the bits of the value. To form the two's complement of a value, simply add one to the value's one's complement.

TERMINOLOGY

base
base 2 number system
base 8 number system
base 10 number system
base 16 number system
binary number system
bitwise complement operator (~)
conversions
decimal number system
digit
hexadecimal number system
negative value
octal number system
one's complement notation
positional notation
positional value
symbol value
two's complement notation

SELF-REVIEW EXERCISES

E.1 The bases of the decimal, binary, octal, and hexadecimal number systems are _____, _____, _____ and _____ respectively.

E.2 In general, the decimal, octal, and hexadecimal representations of a given binary number contain (more/fewer) digits than the binary number contains.

E.3 (True/False) A popular reason for using the decimal number system is that it forms a convenient notation for abbreviating binary numbers simply by substituting one decimal digit per group of four binary bits.

E.4 The (octal / hexadecimal / decimal) representation of a large binary value is the most concise (of the given alternatives).

E.5 (True/False) The highest digit in any base is one more than the base.

E.6 (True/False) The lowest digit in any base is one less than the base.

E.7 The positional value of the rightmost digit of any number in either binary, octal, decimal, or hexadecimal is always _____.

E.8 The positional value of the digit to the left of the rightmost digit of any number in binary, octal, decimal, or hexadecimal is always equal to _____.

E.9 Fill in the missing values in this chart of positional values for the rightmost four positions in each of the indicated number systems:

decimal	1000	100	10	1
hexadecimal	...	256	...	...
binary	...	...	...	...
octal	512	...	8	...

E.10 Convert binary 110101011000 to octal and to hexadecimal.

E.11 Convert hexadecimal FACE to binary.

E.12 Convert octal 7316 to binary.

E.13 Convert hexadecimal 4FEC to octal. (Hint: First convert 4FEC to binary then convert that binary number to octal.)

E.14 Convert binary 1101110 to decimal.

E.15 Convert octal 317 to decimal.

E.16 Convert hexadecimal EFD4 to decimal.

E.17 Convert decimal 177 to binary, to octal, and to hexadecimal.

E.18 Show the binary representation of decimal 417. Then show the one's complement of 417, and the two's complement of 417.

E.19 What is the result when the one's complement of a number is added to itself?

SELF-REVIEW ANSWERS

E.1 10, 2, 8, 16.

E.2 Fewer.

E.3 False.

E.4 Hexadecimal.

E.5 False. The highest digit in any base is one less than the base.

E.6 False. The lowest digit in any base is zero.

E.7 1 (the base raised to the zero power).

E.8 The base of the number system.

E.9 Fill in the missing values in this chart of positional values for the rightmost four positions in each of the indicated number systems:

decimal	**1000**	**100**	**10**	**1**
hexadecimal	**4096**	**256**	**16**	**1**
binary	**8**	**4**	**2**	**1**
octal	**512**	**64**	**8**	**1**

E.10 Octal 6530; Hexadecimal D58.

E.11 Binary 1111 1010 1100 1110.

E.12 Binary 111 011 001 110.

E.13 Binary 0 100 111 111 101 100; Octal 47754.

E.14 Decimal 2+4+8+32+64=110.

E.15 Decimal 7+1*8+3*64=7+8+192=207.

E.16 Decimal 4+13*16+15*256+14*4096=61396.

E.17 Decimal 177
to binary:

```
256 128 64 32 16 8 4 2 1
128 64 32 16 8 4 2 1
(1*128)+(0*64)+(1*32)+(1*16)+(0*8)+(0*4)+(0*2)+(1*1)
10110001
```

to octal:

```
512 64 8 1
64 8 1
(2*64)+(6*8)+(1*1)
261
```

to hexadecimal:

```
256 16 1
16 1
(11*16)+(1*1)
(B*16)+(1*1)
B1
```

E.18 Binary:

```
512 256 128 64 32 16 8 4 2 1
256 128 64 32 16 8 4 2 1
(1*256)+(1*128)+(0*64)+(1*32)+(0*16)+(0*8)+(0*4)+(0*2)+
(1*1)
110100001

One's complement: 001011110
Two's complement: 001011111
Check: Original binary number + its two's complement

110100001
001011111
---------
000000000
```

E.19 Zero.

EXERCISES

E.20 Some people argue that many of our calculations would be easier in the base 12 number system because 12 is divisible by so many more numbers than 10 (for base 10). What is the lowest digit in base 12? What might the highest symbol for the digit in base 12 be? What are the positional values of the rightmost four positions of any number in the base 12 number system?

E.21 How is the highest symbol value in the number systems we discussed related to the positional value of the first digit to the left of the rightmost digit of any number in these number systems?

E.22 Complete the following chart of positional values for the rightmost four positions in each of the indicated number systems:

```
decimal1000100 10  1
base 6 ......  6...
base 13 ... 169... ...
base 3  27.........
```

E.23 Convert binary 100101111010 to octal and to hexadecimal.

E.24 Convert hexadecimal 3A7D to binary.

E.25 Convert hexadecimal 765F to octal. (Hint: First convert 765F to binary, then convert that binary number to octal.)

E.26 Convert binary 1011110 to decimal.

E.27 Convert octal 426 to decimal.

E.28 Convert hexadecimal FFFF to decimal.

E.29 Convert decimal 299 to binary, to octal, and to hexadecimal.

E.30 Show the binary representation of decimal 779. Then show the one's complement of 779, and the two's complement of 779.

E.31 What is the result when the two's complement of a number is added to itself?

E.32 Show the two's complement of integer value -1 on a machine with 32-bit integers.

7

Creating HTML Documentation with `javadoc` (on CD)

Objectives

- To introduce the javadoc J2SDK tool.
- To introduce documentation comments.
- To understand javadoc tags.
- To be able to generate HTML API documentation with javadoc.
- To understand javadoc generated documentation files.

Oh I get by with a little help from my friends.
John Lennon and Paul McCartney

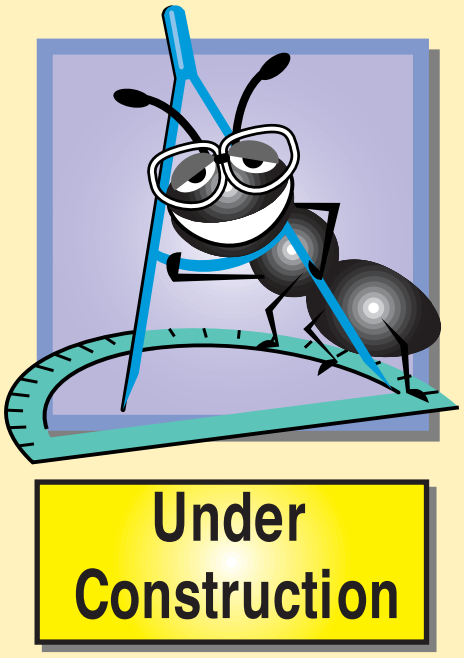
I feel
The link of nature draw me.
John Milton

I think I shall never see
A poem lovely as a tree.
Joyce Kilmer

There is only one religion, though there are a hundred versions of it.
George Bernard Shaw

What I like in a good author is not what he says, but what he whispers.
Logan Pearsall Smith

I shall return.
Douglas MacArthur



Outline

F.1 Introduction
F.2 Documentation Comments
F.3 Documenting Java Source Code
F.4 javadoc
F.5 Files Produced by javadoc

Summary • Terminology

F.1 Introduction

In this appendix, we provide an introduction to the Java 2 Software Developent Kit's **javadoc** utility for creating HTML files that document Java code. This is the tool used by Sun Microsystems to create the Java API documentation (Fig. F.1). We discuss the special Java comments and tags required by **javadoc** to create documentation based on your source code and how to execute the **javadoc** tool.

For detailed information on **javadoc**, visit the **javadoc** home page at

```
java.sun.com/j2se/1.3/docs/tooldocs/javadoc/index.html
```

F.2 Documentation Comments

Before HTML files can be generated with the **javadoc** tool, programmers must insert special comments—called *documentation comments*—into their source files. Documentation comments are the only comments recognized by **javadoc**. Documentation comments begin with **/**** and end with ***/**. An example of a simple documentation comment is

```
/** Sorts integer array using MySort algorithm */
```

Like other comments, documentation comments are not translated into bytecodes. Because **javadoc** is used to create HTML files, documentation comments can contain HTML tags. For example, the documentation comment

```
/** Sorts integer array using <em>MySort</em> algorithm */
```

which contains the HTML emphasis tags **** and **** is valid. In the generated HTML files, **MySort** will appear as emphasized text (normally italic). As we will see, **javadoc** *tags* can be inserted into the documentation comments to help **javadoc** document your source code. These tags—which begin with an **@** symbol—are not HTML tags.

F.3 Documenting Java Source Code

Figure F.2 presents a modified version of the **Time3** class from Fig. 8.8 that contains documentation comments. In the text that follows the example, we thoroughly discuss each of the **javadoc** tags used in the documentation comments. We discuss how to use the **javadoc** tool to generate HTML documentation from this file in Section F.4.

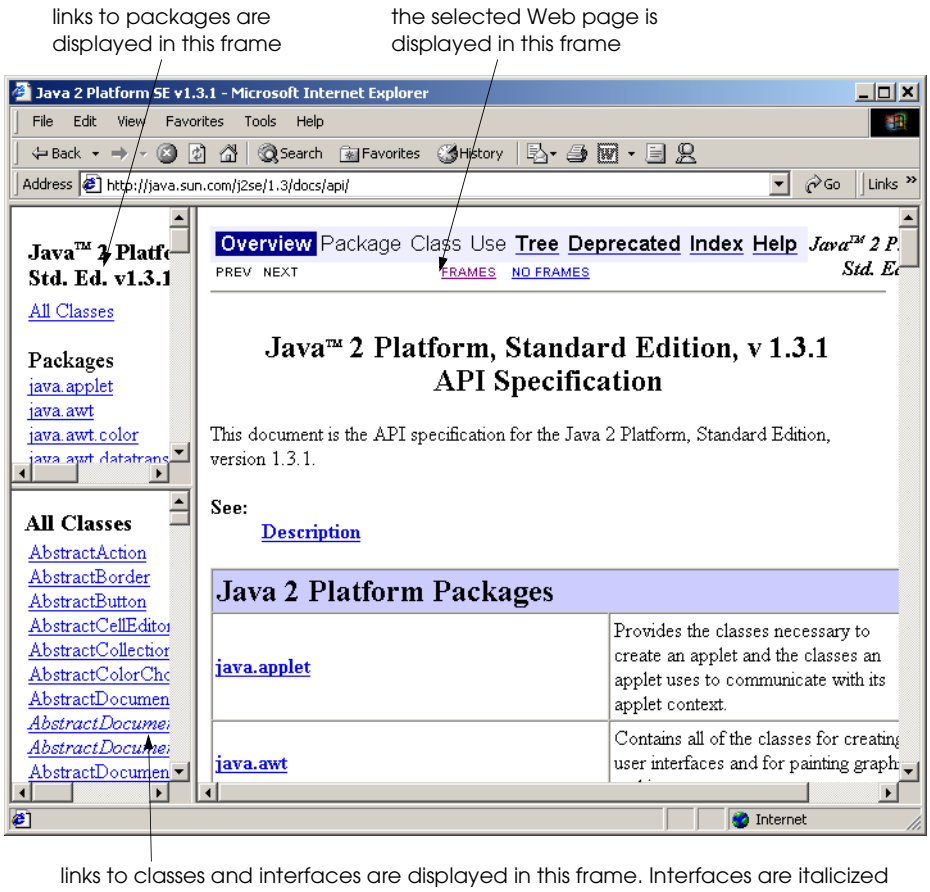


Fig. F.1 Java API documentation.

```
1  // Fig. F.2: Time3.java
2  // Time3 class definition with set and get methods
3  package com.deitel.jhtp4.appenF;
4
5  // Java core packages
6  import java.text.DecimalFormat;
7
8  /**
9   * This class maintains the time in 24-hour format.
10  * @see java.lang.Object
11  * @author Deitel & Associates, Inc.
12  */
13 public class Time3 extends Object {
14
15    private int hour;      // 0 - 23
```

Fig. F.2 A Java source code file containing documentation comments (part 1 of 5).

```
16    private int minute;   // 0 - 59
17    private int second;   // 0 - 59
18
19
20    /**
21     * Time3 constructor initializes each instance variable
22     * to zero. Ensures that Time object starts in a
23     * consistent state.
24     * @throws <code>Exception</code> in the case of an invalid time
25     */
26    public Time3() throws Exception
27    {
28       setTime( 0, 0, 0 );
29    }
30
31
32    /**
33     * Time3 constructor: hour supplied, minute and second
34     * defaulted to 0
35     * @param h the hour
36     * @throws <code>Exception</code> in the case of an invalid time
37     */
38    public Time3( int h ) throws Exception
39    {
40       setTime( h, 0, 0 );
41    }
42
43    /**
44     * Time3 constructor: hour and minute supplied, second
45     * defaulted to 0
46     * @param h the hour
47     * @param m the minute
48     * @throws <code>Exception</code> in the case of an invalid time
49     */
50    public Time3( int h, int m ) throws Exception
51    {
52       setTime( h, m, 0 );
53    }
54
55    /**
56     * Time3 constructor: hour, minute and second supplied
57     * @param h the hour
58     * @param m the minute
59     * @param s the second
60     * @throws <code>Exception</code> in the case of an invalid time
61     */
62    public Time3( int h, int m, int s ) throws Exception
63    {
64       setTime( h, m, s );
65    }
66
```

Fig. F.2 A Java source code file containing documentation comments (part 2 of 5).

```
67      /**
68       * Time3 constructor: another Time3 object supplied
69       * @param time Time3 object
70       * @throws <code>Exception</code> in the case of an invalid time
71       */
72      public Time3( Time3 time ) throws Exception
73      {
74         setTime( time.getHour(), time.getMinute(),
75            time.getSecond() );
76      }
77
78      // Set Methods
79      /**
80       * Set a new time value using universal time. Perform
81       * validity checks on data. Set invalid values to zero.
82       * @param h the hour
83       * @param m the minute
84       * @param s the second
85       * @see com.deitel.jhtp4.appenF.Time3#setHour
86       * @see Time3#setMinute
87       * @see #setSecond
88       * @throws <code>Exception</code> in the case of an invalid time
89       */
90      public void setTime( int h, int m, int s ) throws Exception
91      {
92         setHour( h );    // set the hour
93         setMinute( m );  // set the minute
94         setSecond( s );  // set the second
95      }
96
97      /**
98       * Sets the hour
99       * @param h the hour
100      * @throws Exception in the case of an invalid time
101      */
102     public void setHour( int h ) throws Exception
103     {
104        if ( h >= 0 && h < 24 )
105            hour = h;
106        else
107            throw new Exception();
108     }
109
110     /**
111      * Sets the minute
112      * @param m the minute
113      * @throws Exception in the case of an invalid time
114      */
115     public void setMinute( int m ) throws Exception
116     {
117        if ( m >= 0 && h < 60 )
118           minute = m;
```

Fig. F.2 A Java source code file containing documentation comments (part 3 of 5).

```
119         else
120            throw new Exception();
121      }
122
123      /**
124       * Sets the second
125       * @param m the minute
126       * @throws Exception in the case of an invalid time
127       */
128      public void setSecond( int s ) throws Exception
129      {
130         if ( s >= 0 && s < 60 )
131             second = s;
132         else
133             throw new Exception();
134      }
135
136      // Get Methods
137      /**
138       * Gets the hour
139       * @return an <code>int</code> specifying the hour.
140       */
141      public int getHour()
142      {
143         return hour;
144      }
145
146      /**
147       * Gets the minute
148       * @return an <code>int</code> specifying the minute.
149       */
150      public int getMinute()
151      {
152         return minute;
153      }
154
155      /**
156       * Gets the second
157       * @return an <code>int</code> specifying the second.
158       */
159      public int getSecond()
160      {
161         return second;
162      }
163
164      /**
165       * Convert to <code>String</code> in universal-time format
166       * @return a <code>String</code> representation
167       * of the time in universal-time format
168       */
169      public String toUniversalString()
170      {
171         DecimalFormat twoDigits = new DecimalFormat( "00" );
```

Fig. F.2 A Java source code file containing documentation comments (part 4 of 5).

```
172
173        return twoDigits.format( getHour() ) + ":" +
174           twoDigits.format( getMinute() ) + ":" +
175           twoDigits.format( getSecond() );
176     }
177
178     /**
179      * Convert to <code>String</code> in standard-time format
180      * @return a <code>String</code> representation
181      * of the time in standard-time format
182      */
183     public String toString()
184     {
185        DecimalFormat twoDigits = new DecimalFormat( "00" );
186
187        return ( ( getHour() == 12 || getHour() == 0 ) ?
188           12 : getHour() % 12 ) + ":" +
189           twoDigits.format( getMinute() ) + ":" +
190           twoDigits.format( getSecond() ) +
191           ( getHour() < 12 ? " AM" : " PM" );
192     }
193  }
```

Fig. F.2 A Java source code file containing documentation comments (part 5 of 5).

Documentation comments are placed on the line before a class definition, an interface definition, a constructor, a method and a field (i.e., an instance variable or a reference). The first documentation comment (lines 8–12) introduces class **Time3**. The line

```
* This class maintains the time in 24-hour format.
```

is a description of class **Time3** provided by the programmer. The description can contain as many lines as necessary to provide a description of the class to any programmer who may use it. Tags **@see** and **@author** are used to specify a ***See Also:*** note and an ***Author:*** note, respectively in the HTML documentation (Fig. F.3). The **See Also:** note specifies other related classes that may be of interest to a programmer using this class. The **@author** tag specifies the author of the class. More than one **@author** tag can be used to document multiple authors. Note that the asterisks (*****) on each line between **/**** and ***/** are not required. This is a convention used by programmers to align descriptions and **javadoc** tags. When parsing a documentation comment, **javadoc** discards all whitespace characters up to the first non-whitespace character in each line. If the first non-whitespace character encountered is an asterisk, it is also discarded.

Notice that the documentation comment in lines 8–12 immediately precedes the class definition—any code placed between the documentation comment and the class definition causes **javadoc** to ignore the documentation comment. This is also true of other code structures (e.g., constructors, methods, instance variables, etc.).

Common Programming Error F.1

Placing an ***import*** *statement between the class comment and the class declaration is a logic error. This causes the class comment to be ignored by* ***javadoc****.*

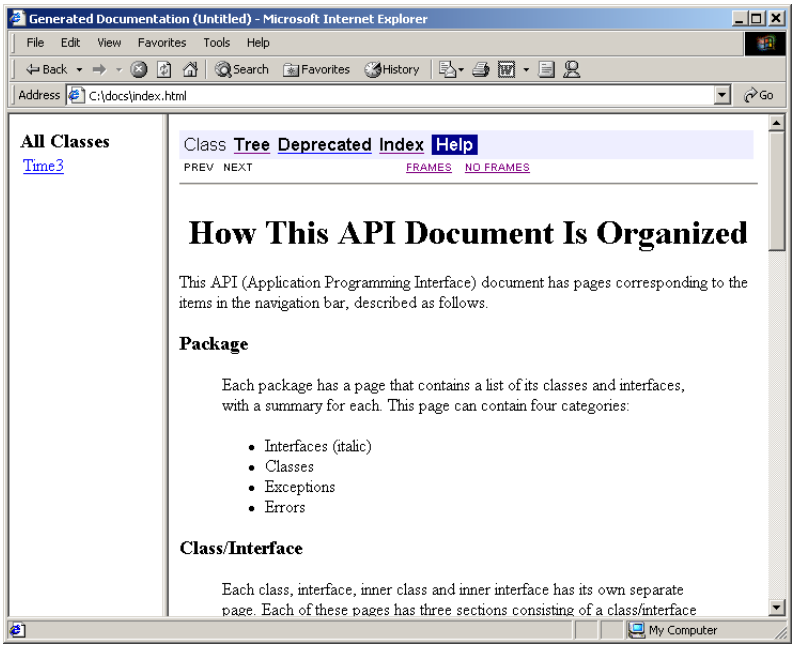


Fig. F.3 HTML documentation for class **`Time3`**.

Software Engineering Observation F.1

Defining several fields in one comma-separated statement with a single comment above that statement, will result in ***`javadoc`*** *using that comment for all of the fields.*

The documentation comment on lines 32–37 describes one of the **`Time3`** constructors. The tag ***`@param`*** describes a parameter to the method. Parameters appear in the HTML document in a **Parameters:** note (Fig. F.4) that is followed by a list of all parameters specified with the **`@param`** tag. For this constructor, the parameter's name is **`h`** and its description is "the hour." Tag **`@param`** can be used only with methods and constructors.

The tag ***`@throws`*** specifies the exceptions thrown by this method. Like **`@param`** tags, **`@throws`** tags are only used with methods and constructors. One **`@throws`** should be supplied for each type of exception thrown by the method.

Software Engineering Observation F.2

To produce proper ***`javadoc`*** *documentation, you must declare every instance variable on a separate line.*

Documentation comments can contain multiple **`@param`** and **`@see`** tags. The documentation comment at lines 79–89 describes method **`setTime`**. The HTML generated for this method is shown in Fig. F.5. Three **`@param`** tags describe the method's parameters. This results in one **Parameters:** note which lists the three parameters. Methods **`setHour`**, **`setMinute`** and **`setSecond`** are tagged with ***`@see`*** to create hyperlinks to their descriptions in the HTML document. A **`#`** character is used instead of a dot when tagging a method or a field. This creates a link to the name that follows the **`#`** character. We demon-

strate three different ways (i.e., the fully qualified name, class name qualification and no qualification) to tag methods using **@see** on lines 85–87. If the fully qualified name is not given (as in lines 86–87), **javadoc** looks for the specified method or field in the following order: current class, superclasses, package and imported files.

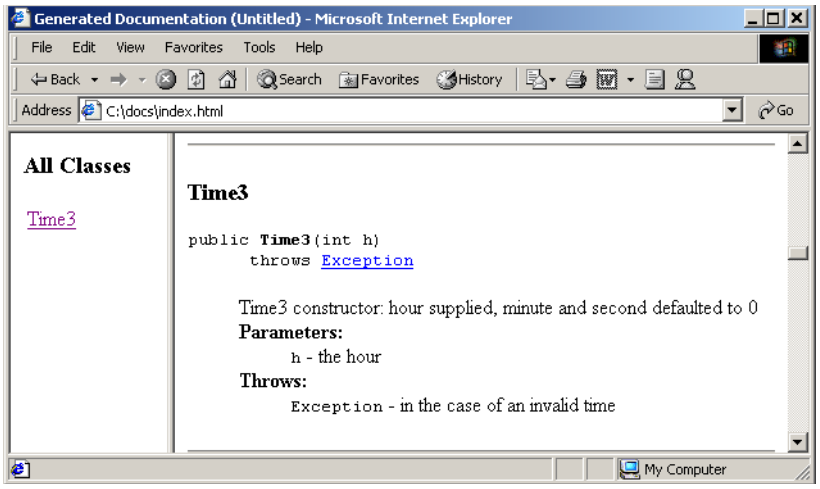


Fig. F.4 The **Parameters:** note generated by javadoc.

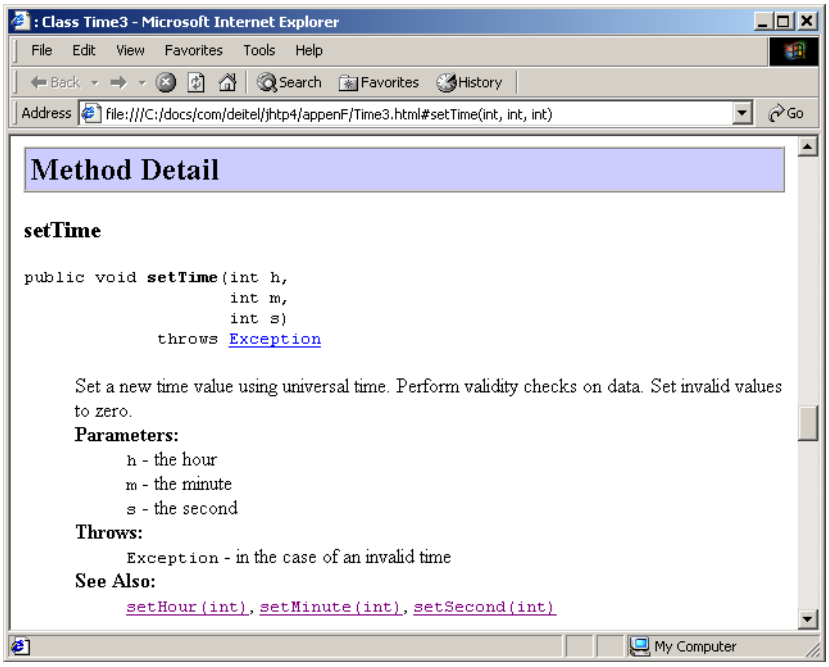


Fig. F.5 HTML documentation for method **setTime**.

The only other tag used in this file is **`@return`** which specifies a **Returns:** note in the HTML documentation (Fig. F.6). The comment at lines 137–140 documents method **`getHour`**. Tag **`@return`** describes a method's return type to help the programmer understand how to use the return value of the method. By **`javadoc`** convention, programmers typeset source code (i.e., keywords, identifiers, expressions, etc.) with the HTML tags **`<code>`** and **`</code>`**.

Good Programming Practice F.1

*Changing source code fonts in **`javadoc`** tags helps code names stand out from the rest of the description.*

In addition to the tags presented in this example, **`javadoc`** recognizes four other tags. Figure F.7 summarizes the most commonly used tags.

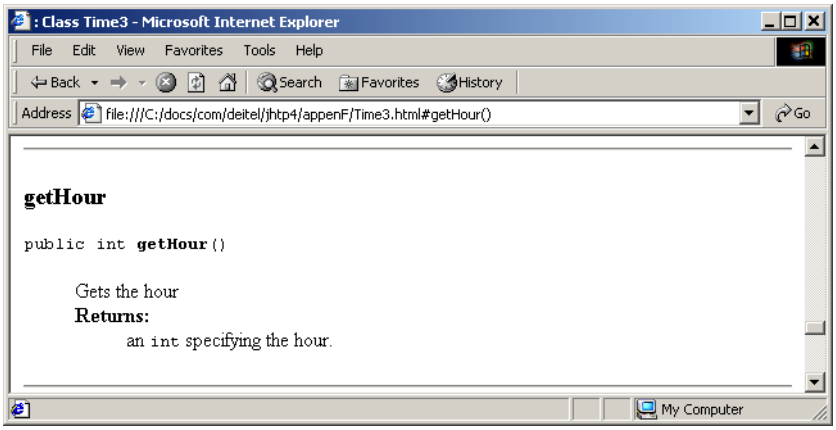


Fig. F.6 HTML documentation for method **`getHour`**.

javadoc tag	Description
`@author`	Adds a **Author:** note if the **`-author`** option is used when executing **`javadoc`**.
`@param`	Used to describe the parameters of methods and constructors.
`@return`	Adds a **Returns:** note describing a methods return type.
`@see`	Adds a **See Also:** note containing hyperlinks to related classes or methods.
`@throws`	Adds a **Throws:** note that specifies the exceptions thrown by the method. **`@exception`** is a synonym for **`@throws`**.
`@deprecated`	Adds a **Deprecated** note. These are notes to programmers indicating that they should not use the specified features of the class. **Deprecated** notes normally appear when a class has been enhanced with new and improved features, but older features are maintained for backwards compatibility.

Fig. F.7 Common **`javadoc`** tags (part 1 of 2).

javadoc tag	Description
`@link`	This allows the programmer to insert an explicit hyperlink to another HTML document.
`@since`	Adds a **Since** note. These notes are used for new versions of a class to indicate when a feature was first introduced. For example, the Java API documentation uses this to indicate features that were introduced in Java 1.0, Java 1.1 and Java 2.
`@version`	Adds a **Version** note. These notes help maintain version number of the software containing the class or method.

Fig. F.7 Common **javadoc** tags (part 2 of 2).

F.4 javadoc

In this section, we discuss how to execute the javadoc tool on a Java source file to create HTML documentation for the class in the file. Like other tools, **javadoc** is executed from the command line. The general form of the **javadoc** command is

javadoc *options packages sources @files*

where *options* is a list of command line options, *package*s is a list of packages the user would like to document, *sources* is a list of java source files to document and **@***files* is a text file containing the names of *packages* and/or *source files* to send to the **javadoc** utility, so that it can create documentation for those packages and classes. The wildcard character ***** can be used to specify multiple sources. (e.g., **c:*.java**) [*Note:* All items are separated by spaces and **@***files* is one word.] Figure F.8 shows a DOS window containing the **javadoc** command we typed to generate the HTML documentation.

In Fig. F.8, the **-d** argument specifies the directory (e.g., **c:\docs**) where the HTML files will be stored on disk. We use the **-link** option so that our documentation links to Sun's documentation. This creates a hyperlink between our documentation and Sun's documentation (see Fig. F.5 where Java class **Exception** from package **java.lang** is hyperlinked). Without the **-link** argument, Exception appears as text in the HTML document—not a hyperlink. The **-author** argument instructs **javadoc** to process the **@author** tag (it ignores this tag by default).

F.5 Files Produced by javadoc

In the last section, we executed the **javadoc** tool on the **Time3.java** file. When **javadoc** executes, it displays the name of each HTML file it creates (see Fig. F.8). From the source file, **javadoc** created an HTML document named **Time3.html** for the class. If the source file contained multiple classes or interfaces, a separate HTML document is created for each class. Because class **Time3** belongs to a package, the page is created in the directory **C:\docs\com\deitel\jhtp4\appenF** (on Win32 platforms). The **c:\docs** directory was specified with the **-d** command line option of **javadoc**, and the remaining directories were created based on the **package** statement.

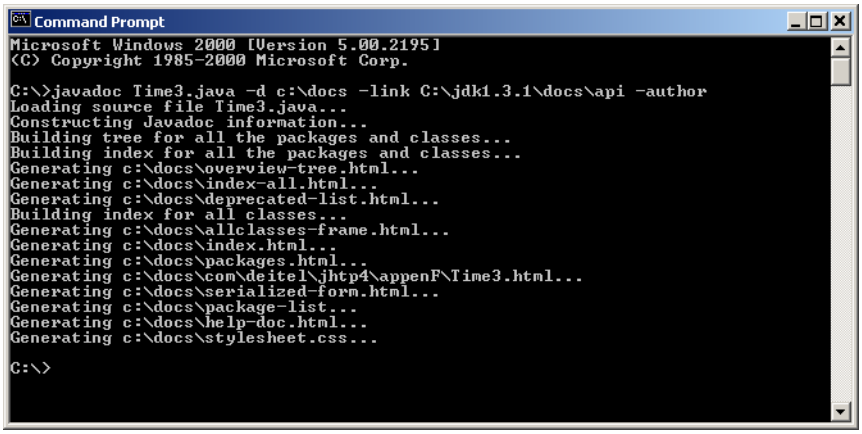


Fig. F.8 Using the **javadoc** tool.

Another file that **javadoc** creates is ***index.html*** the starting HTML page in the documentation. To view the documentation you generate with **javadoc**, load **index.html** into your web browser. In Fig. F.9, the right frame contains the page **index.html** and the left frame contains the page ***allclasses-frame.html*** which contains links to the source code's classes. [*Note:* Because our example does not contain multiple packages, there is no frame listing the packages. Normally this frame would appear above the left frame (containing "All Classes") as in Fig. F.1.]

The *navigation bar* (at the top of the right frame in Fig. F.9) indicates which HTML page is currently loaded by highlighting the page's link (e.g., the **Class** link in Fig. F.9).

Clicking the **Tree** link (Fig. F.10) displays a class hierarchy for all the classes displayed in the left frame. In our example, we documented only class **Time3**—which extends Object. Clicking the **Deprecated** link loads deprecated-list.html into the right frame. This page contains a list of all deprecated names. Because we did not use the **@deprecated** tag in this example, this page does not contain any information. Clicking the **Index** link loads the ***index-all.html*** page which contains an alphabetical list of all classes, interfaces, methods and fields.

Figure F.11 shows class Time3's index-all.html page loaded into a Web browser. Clicking the **Help** link loads ***helpdoc.html*** (Fig. F.12). This is a help file for navigating the documentation. A default help file is provided, however the programmer can specify other help files.

Among the other files generated by **javadoc** are ***serialized-form.html*** which documents Serializable and Externalizable classes and ***package-list.txt*** which is used by the -link command-line argument and is not actually part of the documentation.

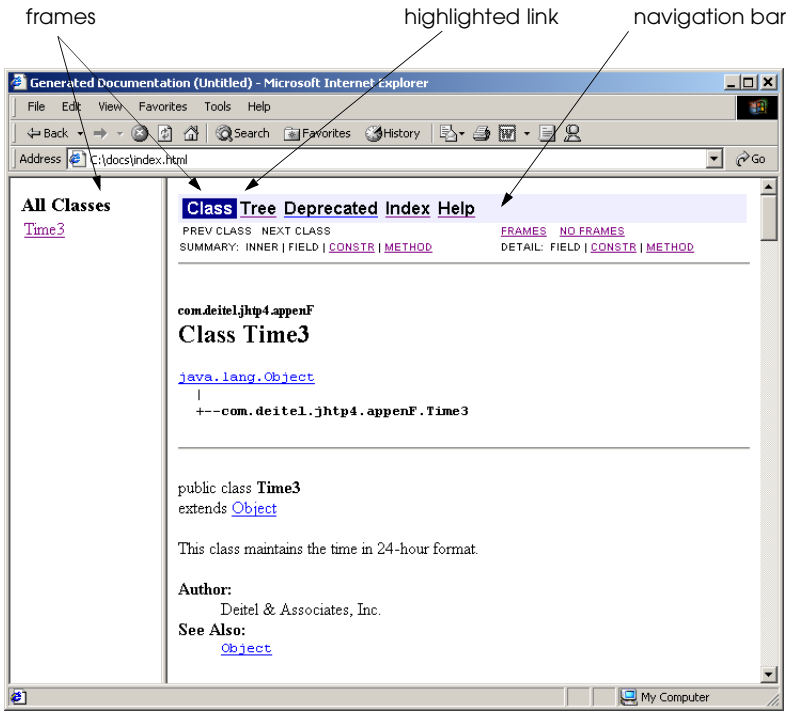


Fig. F.9 Class **`Time3`**'s **`index.html`**.

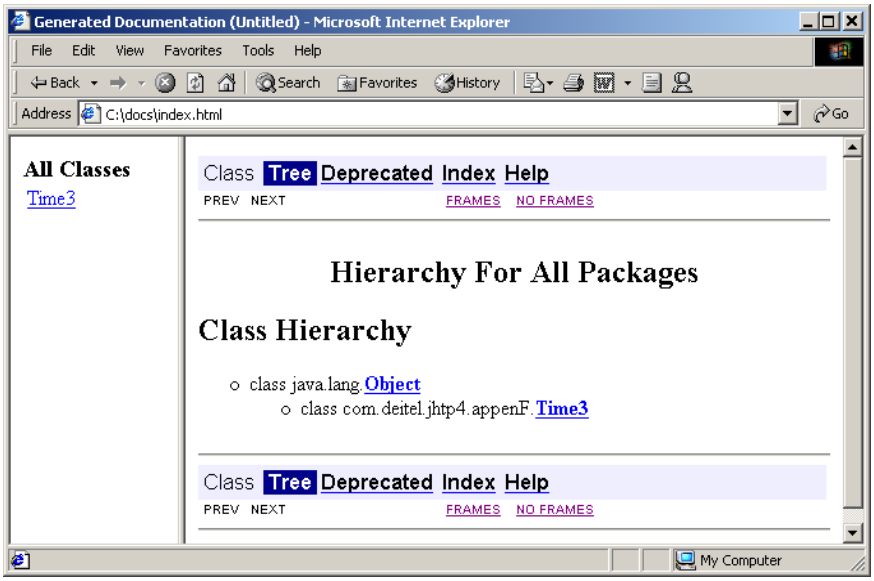


Fig. F.10 **Tree** page.

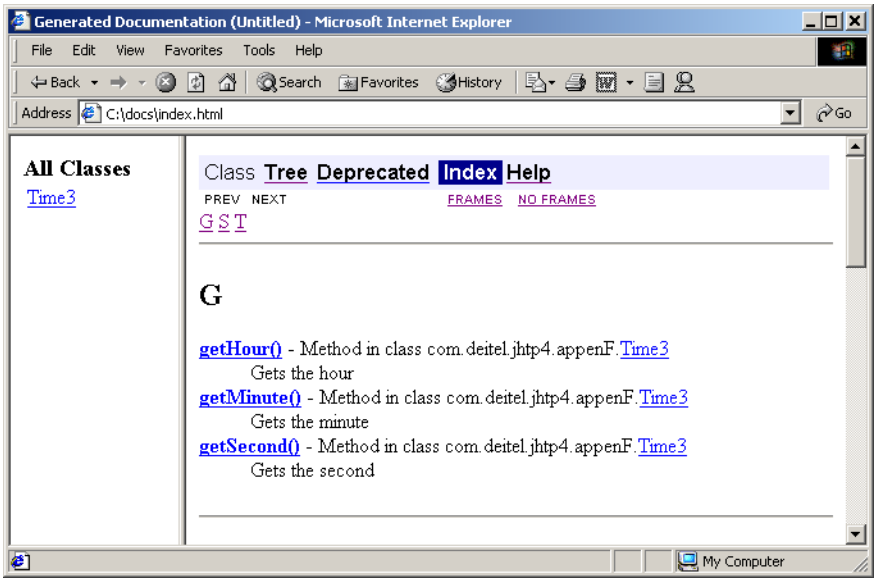


Fig. F.11 Time3's **`index-all.html`** page.

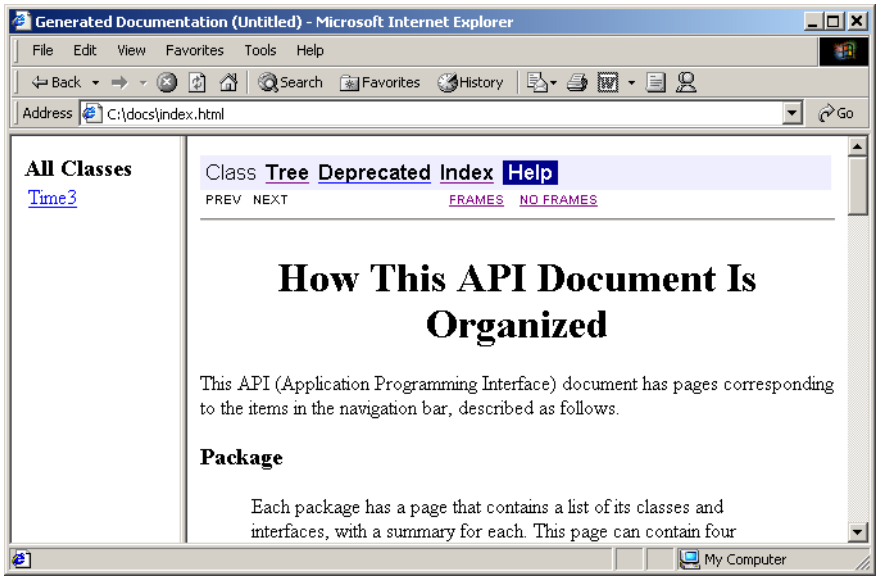


Fig. F.12 Time3's **`helpdoc.html`** page.

TERMINOLOGY

`allclasses-frame.html`
`-author` argument
`@author` **`javadoc`** tag
Class item in the navigator bar
`-d` argument
`deprecated-list.html`
`@deprecated` tag
documentation comment
Exception note
`@exception` tag
Help
`helpdoc.html`
`index.html`
`index-all.html`
`javadoc`
`-link` argument
`@link` tag
`name-frame.html`
Overrides: note
Parameters: note
`@param` tag
Returns: note
`@return` tag
See Also: note
`@see` tag
`serialized-form.html`
`@serial` tag
`@serialData` tag
`@since` tag
`@throws` tag
Tree link
`@version` tag

Elevator Events and Listener Interfaces (on CD)

G.1 Introduction

In "Thinking About Objects" Section 10.22, we discussed how event handling works in our elevator simulation. We mentioned that for an object to receive an event, that object must register as a listener for that event. Therefore, the class of that object must implement an appropriate listener interface that contains methods that receive an event object as a parameter. In this section, we present the events and listener interfaces used in our simulation.

G.2 Events

The next eight figures (Fig. G.1–Fig. G.7) contain the events of the system. Each event inherits from class **`ElevatorModelEvent`** in Fig. G.1. This class contains a **`Location`** reference (line 11) that represent where the event was generated—in our simulation, this reference is the **`Elevator`** object or either **`Floor`** object. Class **`ElevatorModelEvent`** also contains an **`Object`** reference (line 14) representing the source object that generated the event. Methods **`getLocation`** (lines 30–33) and **`getSource`** (lines 42–45) return the **`Location`** and **`Object`** references, respectively. Note that each subclass of **`ElevatorModelEvent`** (Fig. G.2–Fig. G.7) provides only a constructor calling the constructor of class **`ElevatorModelEvent`**. As we mentioned in Section 10.22, dividing class **`ElevatorModelEvent`** into several subclass events makes event handling easier to understand in our simulation.

```
1  // ElevatorModelEvent.java
2  // Basic event packet in Elevator simulation
3  package com.deitel.jhtp4.elevator.event;
4
```

Fig. G.1 **`ElevatorModelEvent`** superclass for events in the elevator simulation model (part 1 of 2).

```
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class ElevatorModelEvent {
9
10    // Location where ElevatorModelEvent was generated
11    private Location location;
12
13    // source Object that generated ElevatorModelEvent
14    private Object source;
15
16    // ElevatorModelEvent constructor sets Location
17    public ElevatorModelEvent( Object source, Location location )
18    {
19       setSource( source );
20       setLocation( location );
21    }
22
23    // set ElevatorModelEvent Location
24    public void setLocation( Location eventLocation )
25    {
26       location = eventLocation;
27    }
28
29    // get ElevatorModelEvent Location
30    public Location getLocation()
31    {
32       return location;
33    }
34
35    // set ElevatorModelEvent source
36    private void setSource( Object eventSource )
37    {
38       source = eventSource;
39    }
40
41    // get ElevatorModelEvent source
42    public Object getSource()
43    {
44       return source;
45    }
46 }
```

Fig. G.1 **ElevatorModelEvent** superclass for events in the elevator simulation model (part 2 of 2).

```
1  // BellEvent.java
2  // Indicates that Bell has rung
3  package com.deitel.jhtp4.elevator.event;
4
```

Fig. G.2 **BellEvent ElevatorModelEvent** subclass indicating that the **Bell** has rung (part 1 of 2).

```
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model*;
7
8  public class BellEvent extends ElevatorModelEvent {
9
10    // BellEvent constructor
11    public BellEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. G.2 **BellEvent ElevatorModelEvent** subclass indicating that the **Bell** has rung (part 2 of 2).

```
1  // ButtonEvent.java
2  // Indicates that a Button has changed state
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class ButtonEvent extends ElevatorModelEvent {
9
10    // ButtonEvent constructor
11    public ButtonEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. G.3 **ButtonEvent ElevatorModelEvent** subclass indicating that a **Button** has changed state.

```
1  // DoorEvent.java
2  // Indicates that a Door has changed state
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class DoorEvent extends ElevatorModelEvent {
9
10    // DoorEvent constructor
11    public DoorEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. G.4 **DoorEvent ElevatorModelEvent** subclass indicating that a **Door** has changed state.

```
1  // ElevatorMoveEvent.java
2  // Indicates on which Floor the Elevator arrived or departed
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class ElevatorMoveEvent extends ElevatorModelEvent {
9
10    // ElevatorMoveEvent constructor
11    public ElevatorMoveEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. G.5 **ElevatorMoveEvent ElevatorModelEvent** subclass indicating on which **Floor** the **Elevator** has either arrived or departed.

```
1  // LightEvent.java
2  // Indicates on which Floor the Light has changed state
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
7
8  public class LightEvent extends ElevatorModelEvent {
9
10    // LightEvent constructor
11    public LightEvent( Object source, Location location )
12    {
13       super( source, location );
14    }
15 }
```

Fig. G.6 **LightEvent ElevatorModelEvent** subclass indicating on which **Floor** the **Light** has changed state.

Class **PersonMoveEvent** (Fig. G.7) has a slightly different structure than that of the other event classes. Line 11 declares **int** attribute **ID**. We will discover in Appendix I that the **ElevatorView** obtains this attribute through method **getID** (lines 22–25) to determine which **Person** sent the event.

```
1  // PersonMoveEvent.java
2  // Indicates that a Person has moved
3  package com.deitel.jhtp4.elevator.event;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.model.*;
```

Fig. G.7 **PersonMoveEvent ElevatorModelEvent** subclass indicating that a **Person** has moved (part 1 of 2).

```
 7
 8  public class PersonMoveEvent extends ElevatorModelEvent {
 9
10     // identifier of Person sending Event
11     private int ID;
12
13     // PersonMoveEvent constructor
14     public PersonMoveEvent( Object source, Location location,
15        int identifier )
16     {
17        super( source, location );
18        ID = identifier;
19     }
20
21     // return identifier
22     public int getID()
23     {
24        return( ID );
25     }
26  }
```

Fig. G.7 **PersonMoveEvent ElevatorModelEvent** subclass indicating that a **Person** has moved (part 2 of 2).

G.3 Listeners

The next eight figures (Fig. G.8–Fig. G.14) contain the listener interfaces for the elevator simulation. **BellListener** (Fig. G.8) provides method **bellRang** (lines 8), which is invoked when the **Bell** has rung. **ButtonListener** (Fig. G.9) provides methods **buttonPressed** (line 8) and **buttonReset** (line 11), which listen when a **Button** is pressed or reset. **DoorListener** (Fig. G.10) provides methods **doorOpened** (line 8) and **doorClosed** (line 11), which listen for a **Door** opening or closing. **ElevatorMoveListener** (Fig. G.11) provides methods **elevatorDeparted** (line 8) and **elevatorArrived** (line 11), which listen for **Elevator** departures and arrivals. **LightListener** (Fig. G.12) provides methods **lightTurnedOn** (line 8) and **lightTurnedOff** (line 11) that listen for **Light** state changes. **PersonMoveListener** (Fig. G.13) provides methods **personCreated** (line 8), **personArrived** (line 11), **personDeparted** (line 14), **personPressedButton** (line 17–18), **personEntered** (line 21) and **personExited** (line 24). These methods listen for when a **Person** has been created, has arrived at or departed from the **Elevator**, pressed a **Button**, entered the **Elevator**, or exited the simulation, respectively. Lastly, **ElevatorModelListener** (Fig. G.14) inherits behaviors from all listener interfaces. The **ElevatorView** uses interface **ElevatorModelListener** in Section 13.17 and Appendix I to receive events from the **ElevatorModel**.

```
1  // BellListener.java
2  // Method invoked when Bell has rung
3  package com.deitel.jhtp4.elevator.event;
4
```

Fig. G.8 Interface **BellListener** method when **Bell** has rung (part 1 of 2).

```
5  public interface BellListener {
6
7     // invoked when Bell has rungs
8     public void bellRang( BellEvent bellEvent );
9  }
```

Fig. G.8 Interface **BellListener** method when **Bell** has rung (part 2 of 2).

```
1  // ButtonListener.java
2  // Methods invoked when Button has been either pressed or reset
3  package com.deitel.jhtp4.elevator.event;
4
5  public interface ButtonListener {
6
7     // invoked when Button has been pressed
8     public void buttonPressed( ButtonEvent buttonEvent );
9
10    // invoked when Button has been reset
11    public void buttonReset( ButtonEvent buttonEvent );
12 }
```

Fig. G.9 Interface **ButtonListener** methods when **Button** has been either pressed or reset.

```
1  // DoorListener.java
2  // Methods invoked when Door has either opened or closed
3  package com.deitel.jhtp4.elevator.event;
4
5  public interface DoorListener {
6
7     // invoked when Door has opened
8     public void doorOpened( DoorEvent doorEvent );
9
10    // invoked when Door has closed
11    public void doorClosed( DoorEvent doorEvent );
12 }
```

Fig. G.10 Interface **DoorListener** methods when **Door** has either opened or closed.

```
1  // ElevatorMoveListener.java
2  // Methods invoked when Elevator has either departed or arrived
3  package com.deitel.jhtp4.elevator.event;
4
5  public interface ElevatorMoveListener {
6
7     // invoked when Elevator has departed
8    public void elevatorDeparted( ElevatorMoveEvent moveEvent );
9
```

Fig. G.11 Interface **ElevatorMoveListener** methods when **Elevator** has either departed from or arrived on a **Floor** (part 1 of 2).

```
10      // invoked when Elevator has arrived
11      public void elevatorArrived( ElevatorMoveEvent moveEvent );
12   }
```

Fig. G.11 Interface **ElevatorMoveListener** methods when **Elevator** has either departed from or arrived on a **Floor** (part 2 of 2).

```
1   // LightListener.java
2   // Methods invoked when Light has either turned on or off
3   package com.deitel.jhtp4.elevator.event;
4
5   public interface LightListener {
6
7      // invoked when Light has turned on
8      public void lightTurnedOn( LightEvent lightEvent );
9
10     // invoked when Light has turned off
11     public void lightTurnedOff( LightEvent lightEvent );
12  }
```

Fig. G.12 Interface **LightListener** method for when **Light** has either turned on or off.

```
1   // PersonMoveListener.java
2   // Methods invoked when Person moved
3   package com.deitel.jhtp4.elevator.event;
4
5   public interface PersonMoveListener {
6
7      // invoked when Person has been instantiated in model
8      public void personCreated( PersonMoveEvent moveEvent );
9
10     // invoked when Person arrived at elevator
11     public void personArrived( PersonMoveEvent moveEvent );
12
13     // invoked when Person departed from elevator
14     public void personDeparted( PersonMoveEvent moveEvent );
15
16     // invoked when Person pressed Button
17     public void personPressedButton(
18        PersonMoveEvent moveEvent );
19
20     // invoked when Person entered Elevator
21     public void personEntered( PersonMoveEvent moveEvent );
22
23     // invoked when Person exited simulation
24     public void personExited( PersonMoveEvent moveEvent );
25  }
```

Fig. G.13 Interface **PersonMoveListener** methods when **Person** has moved.

```
1  // ElevatorModelListener.java
2  // Listener for ElevatorView from ElevatorModel
3  package com.deitel.jhtp4.elevator.event;
4
5  // ElevatorModelListener inherits all Listener interfaces
6  public interface ElevatorModelListener extends BellListener,
7     ButtonListener, DoorListener, ElevatorMoveListener,
8     LightListener, PersonMoveListener {
9  }
```

Fig. G.14 Interface **ElevatorModelListener** allows the model to send all events to the view.

G.4 Component Diagrams Revisited

In Section 13.17, we introduced the component diagram for the elevator simulation. In our simulation, the **ElevatorView** and every object in the model import package **event**. Figure G.15 presents the component diagram for package **event**. Each component in package **event** maps to a class from Fig. G.1–Fig. G.14. According to the component diagram, **ElevatorView.java** of package **view** aggregates package **event**. In Java, this aggregation translates to class **ElevatorView** importing package **event**. Also according to Fig. G.15, package **model** aggregates package **event**—i.e., each component in package **model** contains an aggregation with all components in pacckage event. (We show all components of package **model** in a separate component diagram in Appendix H.) In Java, this aggregation translates to each class in package **model** that imports 'package **event**.

This concludes the appendix on the events and listener interfaces of the elevator simulation. We hope you have found it a useful reference for the material on event handling discussed in "Thinking About Objects" Section 10.22. In the next two appendices, we implement the design for the model and the view, and we provide the component diagrams for packages **model** and **view**.

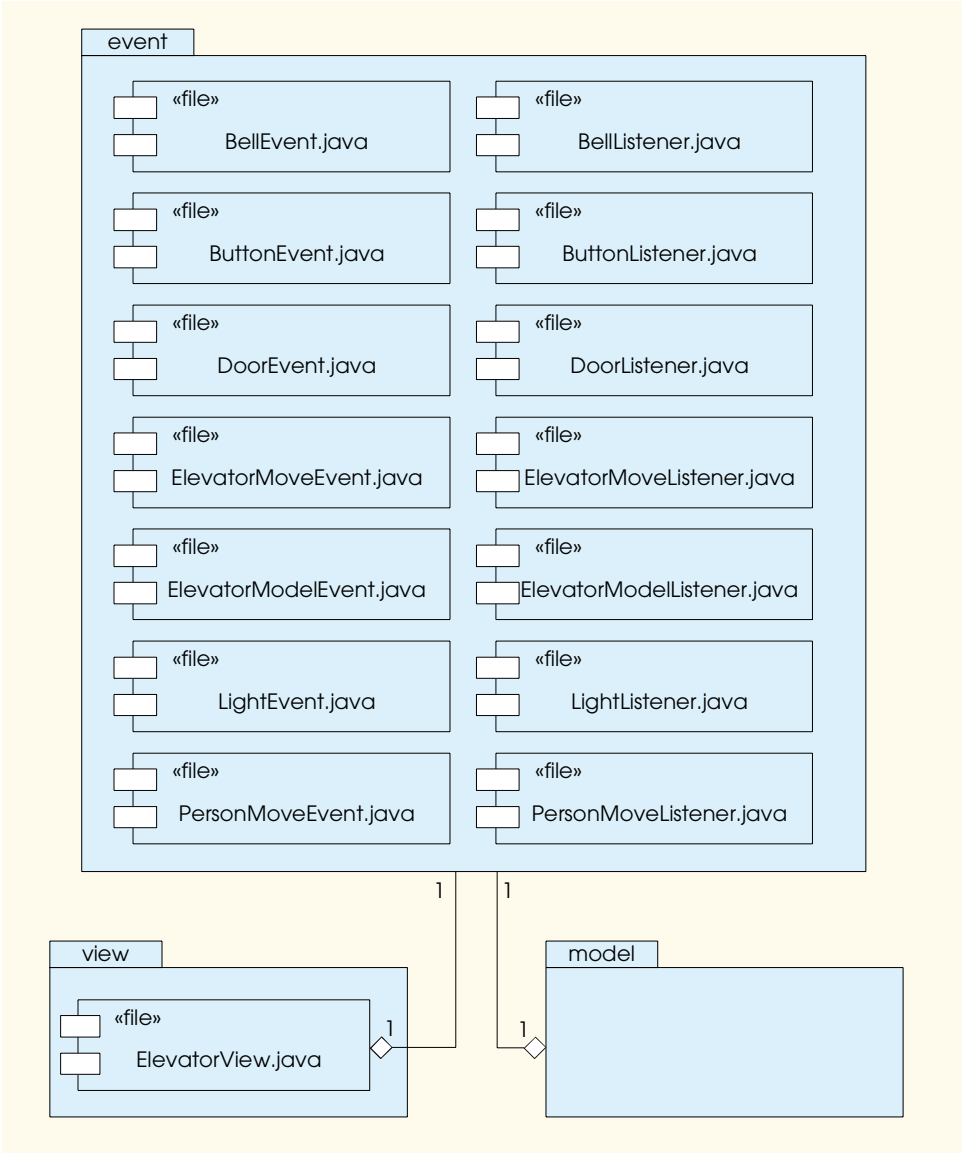


Fig. G.15 Component diagram for package **`event`**.

Elevator Model (on CD)

H.1 Introduction

After reading the "Thinking About Objects" sections, you should have a comfortable grasp of the design process and of the UML diagrams that pertain to our simulation. This appendix presents the code for all 10 classes that collectively represent the model, and concludes the discussion of its workings. We discuss each class separately and in detail.

H.2 Class `ElevatorModel`

As discussed in Section 13.17, class **`ElevatorModel`** (Fig. H.1) ties together the objects that comprise the elevator simulation model. The **`ElevatorModel`** serves to send events from the model to the view. The **`ElevatorModel`** also instantiates new **`Person`**s and allows each **`Floor`** to obtain a reference to the **`ElevatorShaft`**.

```
1  // ElevatorModel.java
2  // Elevator simulation model with ElevatorShaft and two Floors
3  package com.deitel.jhtp4.elevator.model;
4
5  // Java core packages
6  import java.util.*;
7
8  // Deitel packages
9  import com.deitel.jhtp4.elevator.event.*;
10 import com.deitel.jhtp4.elevator.ElevatorConstants;
11
12 public class ElevatorModel implements ElevatorModelListener,
13    ElevatorConstants {
14
```

Fig. H.1 Class **`ElevatorModel`** represents the model in our elevator simulation (part 1 of 7).

```
15    // declare two-Floor architecture in simulation
16    private Floor firstFloor;
17    private Floor secondFloor;
18
19    // ElevatorShaft in simulation
20    private ElevatorShaft elevatorShaft;
21
22    // objects listening for events from ElevatorModel
23    private Set personMoveListeners;
24    private DoorListener doorListener;
25    private ButtonListener buttonListener;
26    private LightListener lightListener;
27    private BellListener bellListener;
28    private ElevatorMoveListener elevatorMoveListener;
29
30    // cumulative number of people in simulation
31    private int numberOfPeople = 0;
32
33    // constructor instantiates ElevatorShaft and Floors
34    public ElevatorModel()
35    {
36       // instantiate firstFloor and secondFloor objects
37       firstFloor = new Floor( FIRST_FLOOR_NAME );
38       secondFloor = new Floor( SECOND_FLOOR_NAME );
39
40       // instantiate ElevatorShaft object
41       elevatorShaft =
42          new ElevatorShaft( firstFloor, secondFloor );
43
44       // give elevatorShaft reference to first and second Floor
45       firstFloor.setElevatorShaft( elevatorShaft );
46       secondFloor.setElevatorShaft( elevatorShaft );
47
48       // register for events from ElevatorShaft
49       elevatorShaft.setDoorListener( this );
50       elevatorShaft.setButtonListener( this );
51       elevatorShaft.addElevatorMoveListener( this );
52       elevatorShaft.setLightListener( this );
53       elevatorShaft.setBellListener( this );
54
55       // instantiate Set for ElevatorMoveListener objects
56       personMoveListeners = new HashSet( 1 );
57
58    } // end ElevatorModel constructor
59
60    // return Floor with given name
61    private Floor getFloor( String name )
62    {
63       if ( name.equals( FIRST_FLOOR_NAME ) )
64          return firstFloor;
65       else
66
```

Fig. H.1 Class **ElevatorModel** represents the model in our elevator simulation (part 2 of 7).

```
67            if ( name.equals( SECOND_FLOOR_NAME ) )
68               return secondFloor;
69            else
70               return null;
71
72      } // end method getFloor
73
74      // add Person to Elevator Simulator
75      public void addPerson( String floorName )
76      {
77         // instantiate new Person and place on Floor
78         Person person =
79            new Person( numberOfPeople, getFloor( floorName ) );
80         person.setName( Integer.toString( numberOfPeople ) );
81
82         // register listener for Person events
83         person.setPersonMoveListener( this );
84
85         // start Person thread
86         person.start();
87
88         // increment number of Person objects in simulation
89         numberOfPeople++;
90
91      } // end method addPerson
92
93      // invoked when Elevator has departed from Floor
94      public void elevatorDeparted(
95         ElevatorMoveEvent moveEvent )
96      {
97         elevatorMoveListener.elevatorDeparted( moveEvent );
98      }
99
100     // invoked when Elevator has arrived at destination Floor
101     public void elevatorArrived(
102        ElevatorMoveEvent moveEvent )
103     {
104        elevatorMoveListener.elevatorArrived( moveEvent );
105     }
106
107     // send PersonMoveEvent to listener, depending on event type
108     private void sendPersonMoveEvent(
109        int eventType, PersonMoveEvent event )
110     {
111        Iterator iterator = personMoveListeners.iterator();
112
113        while ( iterator.hasNext() ) {
114
115           PersonMoveListener listener =
116              ( PersonMoveListener ) iterator.next();
117
```

Fig. H.1 Class **ElevatorModel** represents the model in our elevator simulation (part 3 of 7).

```
118          // send Event to this listener, depending on eventType
119          switch ( eventType ) {
120
121             // Person has been created
122             case Person.PERSON_CREATED:
123                listener.personCreated( event );
124                break;
125
126             // Person arrived at Elevator
127             case Person.PERSON_ARRIVED:
128                listener.personArrived( event );
129                break;
130
131             // Person entered Elevator
132             case Person.PERSON_ENTERING_ELEVATOR:
133                listener.personEntered( event );
134                break;
135
136             // Person pressed Button object
137             case Person.PERSON_PRESSING_BUTTON:
138                listener.personPressedButton( event );
139                break;
140
141             // Person exited Elevator
142             case Person.PERSON_EXITING_ELEVATOR:
143                listener.personDeparted( event );
144                break;
145
146             // Person exited simulation
147             case Person.PERSON_EXITED:
148                listener.personExited( event );
149                break;
150
151             default:
152                break;
153          }
154       }
155    } // end method sendPersonMoveEvent
156
157    // invoked when Person has been created in model
158    public void personCreated( PersonMoveEvent moveEvent )
159    {
160       sendPersonMoveEvent( Person.PERSON_CREATED, moveEvent );
161    }
162
163    // invoked when Person has arrived at Floor's Button
164    public void personArrived( PersonMoveEvent moveEvent )
165    {
166       sendPersonMoveEvent( Person.PERSON_ARRIVED, moveEvent );
167    }
168
```

Fig. H.1 Class **ElevatorModel** represents the model in our elevator simulation (part 4 of 7).

```
169    // invoked when Person has pressed Button
170    public void personPressedButton( PersonMoveEvent moveEvent )
171    {
172       sendPersonMoveEvent( Person.PERSON_PRESSING_BUTTON,
173          moveEvent );
174    }
175
176    // invoked when Person has entered Elevator
177    public void personEntered( PersonMoveEvent moveEvent )
178    {
179       sendPersonMoveEvent( Person.PERSON_ENTERING_ELEVATOR,
180          moveEvent );
181    }
182
183    // invoked when Person has departed from Elevator
184    public void personDeparted( PersonMoveEvent moveEvent )
185    {
186       sendPersonMoveEvent( Person.PERSON_EXITING_ELEVATOR,
187          moveEvent );
188    }
189
190    // invoked when Person has exited Simulation
191    public void personExited( PersonMoveEvent moveEvent )
192    {
193       sendPersonMoveEvent( Person.PERSON_EXITED, moveEvent );
194    }
195
196    // invoked when Door has opened
197    public void doorOpened( DoorEvent doorEvent )
198    {
199       doorListener.doorOpened( doorEvent );
200    }
201
202    // invoked when Door has closed
203    public void doorClosed( DoorEvent doorEvent )
204    {
205       doorListener.doorClosed( doorEvent );
206    }
207
208    // invoked when Button has been pressed
209    public void buttonPressed( ButtonEvent buttonEvent )
210    {
211       buttonListener.buttonPressed( buttonEvent );
212    }
213
214    // invoked when Button has been reset
215    public void buttonReset( ButtonEvent buttonEvent )
216    {
217       buttonListener.buttonReset( buttonEvent );
218    }
219
```

Fig. H.1 Class **`ElevatorModel`** represents the model in our elevator simulation (part 5 of 7).

```
220    // invoked when Bell has rung
221    public void bellRang( BellEvent bellEvent )
222    {
223       bellListener.bellRang( bellEvent );
224    }
225
226    // invoked when Light has turned on
227    public void lightTurnedOn( LightEvent lightEvent )
228    {
229       lightListener.lightTurnedOn( lightEvent );
230    }
231
232    // invoked when Light has turned off
233    public void lightTurnedOff( LightEvent lightEvent )
234    {
235       lightListener.lightTurnedOff( lightEvent );
236    }
237
238    // set listener for ElevatorModelListener
239    public void setElevatorModelListener(
240       ElevatorModelListener listener )
241    {
242       // ElevatorModelListener extends all interfaces below
243       addPersonMoveListener( listener );
244       setElevatorMoveListener( listener );
245       setDoorListener( listener );
246       setButtonListener( listener );
247       setLightListener( listener );
248       setBellListener( listener );
249    }
250
251    // set listener for PersonMoveEvents
252    public void addPersonMoveListener(
253       PersonMoveListener listener )
254    {
255       personMoveListeners.add( listener );
256    }
257
258    // set listener for DoorEvents
259    public void setDoorListener( DoorListener listener )
260    {
261       doorListener = listener;
262    }
263
264    // set listener for ButtonEvents
265    public void setButtonListener( ButtonListener listener )
266    {
267       buttonListener = listener;
268    }
269
```

Fig. H.1 Class **`ElevatorModel`** represents the model in our elevator simulation (part 6 of 7).

```
270    // add listener for ElevatorMoveEvents
271    public void setElevatorMoveListener(
272       ElevatorMoveListener listener )
273    {
274       elevatorMoveListener = listener;
275    }
276
277    // set listener for LightEvents
278    public void setLightListener( LightListener listener )
279    {
280       lightListener = listener;
281    }
282
283    // set listener for BellEvents
284    public void setBellListener( BellListener listener )
285    {
286       bellListener = listener;
287    }
288 }
```

Fig. H.1 Class **ElevatorModel** represents the model in our elevator simulation (part 7 of 7).

The class diagram in Fig. 15.21 shows that class **ElevatorModel** contains one instance of class **ElevatorShaft** and two instances of class **Floor**, so **ElevatorModel** declares object **elevatorShaft** (line 20) and objects **firstFloor** and **secondFloor** (lines 16–17). Lines 37–46 instantiate these objects and give each **Floor** object a reference to the **ElevatorShaft** object. Fig. 15.21 also shows that class **ElevatorModel** creates **Person** objects. According to Fig. 15.21, class **ElevatorModel** contains method **addPerson** (lines 75–91), which creates and places a **Person** on the specified **Floor**. Line 86 of method **addPerson** starts the **Person**'s thread and line 89 increments the cumulative number of **Person** objects in the simulation.

As previously mentioned, class **ElevatorModel** sends events from the model to the view. The class declaration (lines 12–13) and lines 49–53 reveal that the **ElevatorModel** listens for several types of events from the **ElevatorShaft**—this is how the **ElevatorModel** receives events from the objects that comprise the model. Specifically, class **ElevatorModel** implements interface **ElevatorModelListener**, which implements all interfaces in package **event**. Lines 23–28 declare the listener objects to which the **ElevatorModel** sends the events it receives from the **ElevatorShaft**. As mentioned in Section 13.17, the **ElevatorFrame** (the application) registers the **ElevatorView** as a listener for events from the **ElevatorModel**—this is how the **ElevatorModel** sends events from the model to the view.

Lines 94–236 of class **ElevatorModel** implement all methods of interface **ElevatorModelListener**, and lines 239–288 provide **addListener** methods to register a listener (in this case, the listener is the **ElevatorView**) for all events. In fact, two-thirds of the class devotes itself to "bubbling up" messages from the model to the view.

We presented a class diagram that showed the realizations of the elevator model in Fig. 11.27. We alter this diagram to accommodate the fact that class **ElevatorModel** implements all interfaces through interface **ElevatorModelListener**. In addition, class **ElevatorShaft** must implement more interfaces to receive events from class

`Elevator` so that **`ElevatorShaft`** can send these events to the **`ElevatorModel`**. We present the class diagram showing all realizations for the model in Fig. H.2 and Fig. H.3—Fig. H.2 shows the relationship between the classes in the model and the listener interfaces, and Fig. H.3 shows the relationship between the listener interfaces and interface **`ElevatorModelListener`** (we could have created one class diagram showing both types of relationships, but the diagram would have been too cluttered).

Figure H.4 describes the contents of the class diagram that shows elevator model realizations. The substantial changes are that class **`ElevatorShaft`** now implements interface **`ElevatorMoveListener`**, and **`ElevatorModel`** implements interface **`ElevatorModelListener`**, which implements all interfaces.

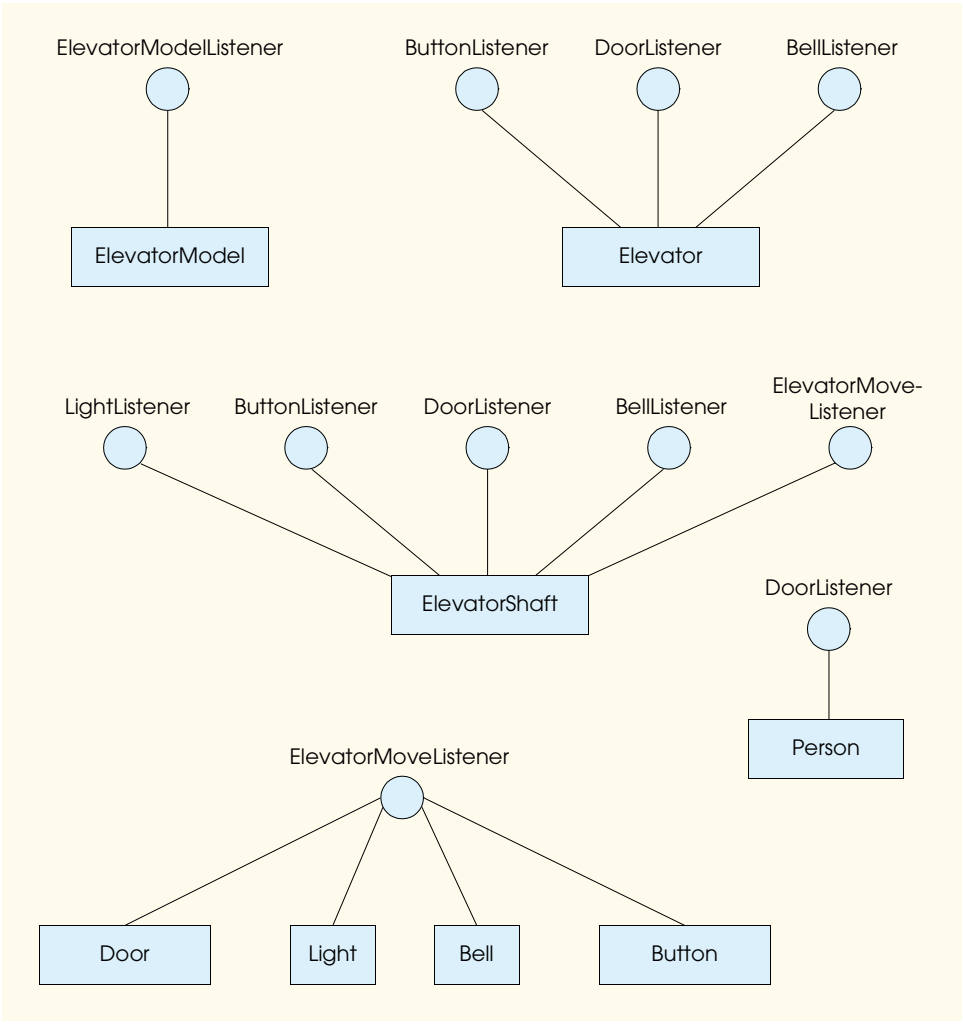


Fig. H.2 Class diagram showing realizations in the elevator model (Part 1).

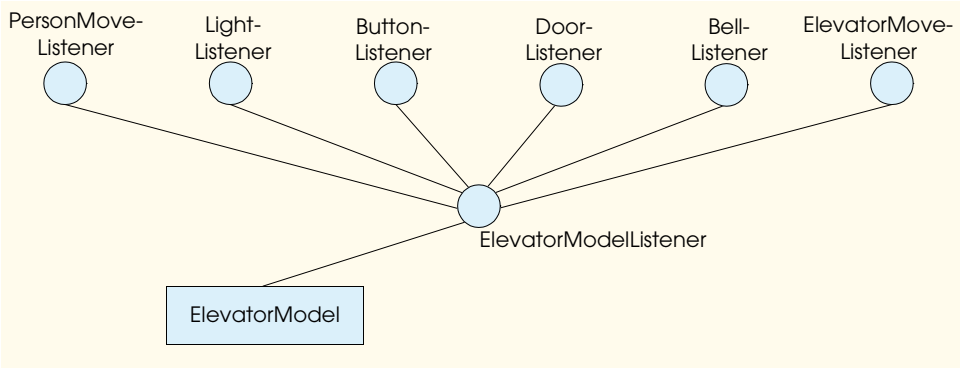


Fig. H.3 Class diagram showing realizations in the elevator model (Part 2).

Class	implements Listener
`ElevatorModel`	`ElevatorModelListener`

`ElevatorModelListener`	`PersonMoveListener`
	`ElevatorMoveListener`
	`ButtonListener`
	`DoorListener`
	`BellListener`
	`LightListener`

`Door, Light, Bell, Button`	`ElevatorMoveListener`

`Elevator`	`ButtonListener`
	`DoorListener`
	`BellListener`

`ElevatorShaft`	`LightListener`
	`ButtonListener`
	`DoorListener`
	`BellListener`
	`ElevatorMoveListener`

`Person`	`DoorListener`

Fig. H.4 Classes and implemented listener interfaces from Fig. H.2.

H.3 Classes `Location` and `Floor`

We need to represent the location of the **`Person`** in the simulation. The **`Person`** could have an **`int`** attribute describing on which **`Floor`** the **`Person`** is walking; however, the **`Person`** does not occupy either **`Floor`** when riding the **`Elevator`**. As described in "Thinking About Objects" Section 9.23, our solution is for the **`Person`** to maintain a **`Location`** reference, which references either a **`Floor`** or the **`Elevator`**, depending on the whereabouts of the **`Person`**. To implement this feature, classes **`Floor`** and **`Elevator`** extend abstract superclass **`Location`** (Fig. H.5).

```
1  // Location.java
2  // Abstract superclass representing location in simulation
3  package com.deitel.jhtp4.elevator.model;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.event.*;
7
8  public abstract class Location {
9
10    // name of Location
11    private String locationName;
12
13    // set name of Location
14    protected void setLocationName( String name )
15    {
16       locationName = name;
17    }
18
19    // return name of Location
20    public String getLocationName()
21    {
22       return locationName;
23    }
24
25    // return Button at Location
26    public abstract Button getButton();
27
28    // return Door object at Location
29    public abstract Door getDoor();
30 }
```

Fig. H.5 **`Location`** abstract superclass that represents a location in the simulation.

`Location` contains **`String locationName`** (line 11), which may contain either value **`firstFloor`**, **`secondFloor`** or **`elevator`** to describe the three locations the **`Person`** may occupy. Lines 26 and 29 declare abstract methods **`getButton`** and **`getDoor`**, respectively. Using these methods, a **`Floor`** returns references to objects associated with that **`Floor`**, and the **`Elevator`** returns references to the objects associated with the **`Elevator`**. The **`Location`** reference allows a **`Person`** to press a **`Button`** and to know when a **`Door`** has opened. For example, if we wish a **`Person`** to press a **`Button`**, we write

```
person.getLocation().getButton().pressButton();
```

Therefore, our use of an abstract superclass provides an alternate means for objects in our model to interact. Figure H.6 presents class **`Floor`**, a subclass of class **`Location`**. The **`Floor`** constructor (lines 15–18) takes as a **`String`** argument the value **`firstFloor`** or **`secondFloor`** to identify the **`Floor`**. Line 17 invokes method **`setLocationName`** to assign the value of this **`String`** to attribute **`locationName`**, inherited from superclass **`Location`**.

```
1  // Floor.java
2  // Represents a Floor located next to an ElevatorShaft
3  package com.deitel.jhtp4.elevator.model;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.ElevatorConstants;
7
8  public class Floor extends Location
9     implements ElevatorConstants {
10
11    // reference to ElevatorShaft object
12    private ElevatorShaft elevatorShaft;
13
14    // Floor constructor sets name of Floor
15    public Floor( String name )
16    {
17       setLocationName( name );
18    }
19
20    // get first or second Floor Button, using Location name
21    public Button getButton()
22    {
23       if ( getLocationName().equals( FIRST_FLOOR_NAME ) )
24          return getElevatorShaft().getFirstFloorButton();
25       else
26
27          if ( getLocationName().equals( SECOND_FLOOR_NAME ) )
28             return getElevatorShaft().getSecondFloorButton();
29       else
30
31          return null;
32
33    } // end method getButton
34
35    // get first or second Floor Door, using Location name
36    public Door getDoor()
37    {
38       if ( getLocationName().equals( FIRST_FLOOR_NAME ) )
39          return getElevatorShaft().getFirstFloorDoor();
40       else
41
42          if ( getLocationName().equals( SECOND_FLOOR_NAME ) )
43             return getElevatorShaft().getSecondFloorDoor();
44       else
45
46          return null;
47
48    } // end method getDoor
49
50    // get ElevatorShaft reference
51    public ElevatorShaft getElevatorShaft()
52    {
```

Fig. H.6 Class **Floor**—a subclass of **Location**—represents a **Floor** across which a **Person** walks to the **Elevator** (part 1 of 2).

```
53          return elevatorShaft;
54       }
55
56       // set ElevatorShaft reference
57       public void setElevatorShaft( ElevatorShaft shaft )
58       {
59          elevatorShaft = shaft;
60       }
61    }
```

Fig. H.6 Class **Floor**—a subclass of **Location**—represents a **Floor** across which a **Person** walks to the **Elevator** (part 2 of 2).

Class **Floor** provides concrete methods **getButton** (lines 21–33) and **getDoor** (lines 36–48). Methods **getButton** and **getDoor** return a **Button** and **Door** reference on either the first or second **Floor**, depending on which **Floor** returns the reference. Lastly, method **getElevatorShaft** (lines 51–54) returns a reference to the **ElevatorShaft**. We will see later how a **Person** uses this method, in conjunction with that **Person**'s **Location** reference, to enter the **Elevator**.

H.4 Class Door

The **Door**s are an essential part of the model, because they inform a **Person** when to enter and exit the **Elevator**—without the **Door**s, no **Person** would ride the **Elevator**. The collaboration diagrams of Fig. 7.20, Fig. 10.25 and Fig. 15.18 presented the collaborations among the **Door**s, the **Elevator** and the **Person**. Now, we provide a walkthrough of class **Door** (Fig. H.7).

```
1  // Door.java
2  // Sends DoorEvents to DoorListeners when opened or closed
3  package com.deitel.jhtp4.elevator.model;
4
5  // Java core packages
6  import java.util.*;
7
8  // Deitel packages
9  import com.deitel.jhtp4.elevator.event.*;
10
11 public class Door implements ElevatorMoveListener {
12
13    // represent whether Door is open or closed
14    private boolean open = false;
15
16    // time before Door closes automatically
17    public static final int AUTOMATIC_CLOSE_DELAY = 3000;
18
19    // Set of DoorListeners
20    private Set doorListeners;
21
```

Fig. H.7 Class **Door**, which represents a **Door** in the model, informs listeners when a **Door** has opened or closed (part 1 of 4).

```
22    // location where Door opened or closed
23    private Location doorLocation;
24
25    // Door constructor instantiates Set for DoorListeners
26    public Door()
27    {
28       doorListeners = new HashSet( 1 );
29    }
30
31    // add Door listener
32    public void addDoorListener( DoorListener listener )
33    {
34       // prevent other objects from modifying doorListeners
35       synchronized( doorListeners )
36       {
37          doorListeners.add( listener );
38       }
39    }
40
41    // remove Door listener
42    public void removeDoorListener( DoorListener listener )
43    {
44       // prevent other objects from modifying doorListeners
45       synchronized( doorListeners )
46       {
47          doorListeners.remove( listener );
48       }
49    }
50
51    // open Door and send all listeners DoorEvent objects
52    public void openDoor( Location location )
53    {
54       if ( !open ) {
55
56          open = true;
57
58          // obtain iterator from Set
59          Iterator iterator;
60          synchronized( doorListeners )
61          {
62             iterator = new HashSet( doorListeners ).iterator();
63          }
64
65          // get next DoorListener
66          while ( iterator.hasNext() ) {
67             DoorListener doorListener =
68                ( DoorListener ) iterator.next();
69
70             // send doorOpened event to this DoorListener
71             doorListener.doorOpened(
72                new DoorEvent( this, location ) );
73          }
```

Fig. H.7 Class **Door**, which represents a **Door** in the model, informs listeners when a **Door** has opened or closed (part 2 of 4).

```
74
75          doorLocation = location;
76
77          // declare Thread that ensures automatic Door closing
78          Thread closeThread = new Thread(
79             new Runnable() {
80
81                public void run()
82                {
83                   // close Door if open for more than 3 seconds
84                   try {
85                      Thread.sleep( AUTOMATIC_CLOSE_DELAY );
86                      closeDoor( doorLocation );
87                   }
88
89                   // handle exception if interrupted
90                   catch ( InterruptedException exception ) {
91                      exception.printStackTrace();
92                   }
93                }
94             } // end anonymous inner class
95          );
96
97          closeThread.start();
98       }
99    } // end method openDoor
100
101   // close Door and send all listeners DoorEvent objects
102   public void closeDoor( Location location )
103   {
104      if ( open ) {
105
106         open = false;
107
108         // obtain iterator from Set
109         Iterator iterator;
110         synchronized( doorListeners )
111         {
112            iterator = new HashSet( doorListeners ).iterator();
113         }
114
115         // get next DoorListener
116         while ( iterator.hasNext() ) {
117            DoorListener doorListener =
118               ( DoorListener ) iterator.next();
119
120            // send doorClosed event to this DoorListener
121            doorListener.doorClosed(
122               new DoorEvent( this, location ) );
123         }
124      }
125   } // end method closeDoor
```

Fig. H.7 Class **Door**, which represents a **Door** in the model, informs listeners when a **Door** has opened or closed (part 3 of 4).

```
126
127    // return whether Door is open or closed
128    public boolean isDoorOpen()
129    {
130       return open;
131    }
132
133    // invoked after Elevator has departed
134    public void elevatorDeparted( ElevatorMoveEvent moveEvent ) {}
135
136    // invoked when Elevator has arrived
137    public void elevatorArrived( ElevatorMoveEvent moveEvent )
138    {
139       openDoor( moveEvent.getLocation() );
140    }
141 }
```

Fig. H.7 Class **Door**, which represents a **Door** in the model, informs listeners when a **Door** has opened or closed (part 4 of 4).

Figure 15.12 indicates that class **Door** contains **boolean** attribute **open** (line 14) to represent the state of the **Door** (open or closed). Figure 15.12 also indicates that class **Door** contains methods **openDoor** (lines 52–99) and **closeDoor** (lines 102–125). Method **openDoor** sends a **doorOpened** event to all registered **DoorListener**s (the **Door** passes a **DoorEvent** object to the **doorOpened** method of each registered **DoorListener**), and method **closeDoor** sends a **doorClosed** event to all registered **DoorListener**s. **Set doorListeners** (line 20) stores all registered **DoorListener**s. A **DoorListener** wishing to receive **DoorEvent**s from a **Door** must invoke method **addDoorListener** (lines 32–39); those listeners that no longer wish to be a **DoorListener** for that **Door** must invoke **removeDoorListener** (lines 42–49).

Line 56 of method **openDoor** opens the **Door** by setting **open** to **true**. Lines 66–73 iterate **Set doorListeners** and send each object a **doorOpened** event. Lines 60–63 use a **synchronized** block obtaining the **Iterator** from **Set doorListeners**, because a **Person**, at any time, can add or remove itself from this **Set**. If method **openDoor** iterates **doorListeners** as a **Person** adds or removes itself from **doorListeners**, the JVM throws a **ConcurrentModificationException**—the **Person** is modifying the **Set** as method **openDoor** is iterating the same **Set**. Method **openDoor** avoids this situation with the **synchronized** block.

Method **openDoor** receives as an argument a **Location** reference on what **Floor** that **Door** should open. Lines 71–72 send a **DoorEvent** using the **Location** reference to all registered **DoorListener**s. Method **closeDoor** sets **open** to **false** (thus closing the **Door**) and invokes the **doorClosed** method on all registered **DoorListener**s.

We decided in Section 15.12 to make class **Door** an active class, so that the **Door** closes itself after three seconds of being open. Lines 78–95 of method **openDoor** instantiate a thread that handles this responsibility. Method **run** (lines 81–93) puts this thread to sleep for three seconds then closes the **Door**. Line 97 of method **openDoor** starts the thread.

Lastly, according to Fig. H.2, **Door** implements **ElevatorMoveListener**. In our simulation, the **Elevator** invokes method **elevatorDeparted** (line 134) when the

Elevator has departed and invokes method **elevatorArrived** (lines 137–140) when the **Elevator** has arrived. Method **elevatorArrived** calls method **openDoor**—the **Door** opens when the **Elevator** has arrived. Method **elevatorDeparted** does not perform any action. At a first glance, you may wonder why this method does not call method **closeDoor**. The reason is that a **Door** should close *before* the **Elevator** has departed so the passenger will not be injured—in our model, the **Elevator** calls method **closeDoor** before calling **elevatorDeparted**.

H.5 Class Button

Buttons (Fig. H.8) are important to the model as well, because they signal the **Elevator** to move between **Floor**s. Figure 15.12 indicates that class **Button** contains **boolean** attribute **pressed** (line 14) to represent the state of the **Button** (pressed or reset). Figure 15.12 indicates also that class **Button** contains methods **pressButton** (lines 23–29) and **resetButton** (lines 32–38).

```
1  // Button.java
2  // Sends ButtonEvents to ButtonListeners when accessed
3  package com.deitel.jhtp4.elevator.model;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.event.*;
7
8  public class Button implements ElevatorMoveListener {
9
10    // ButtonListener
11    private ButtonListener buttonListener = null;
12
13    // represent whether Button is pressed
14    private boolean pressed = false;
15
16    // set listener
17    public void setButtonListener( ButtonListener listener )
18    {
19       buttonListener = listener;
20    }
21
22    // press Button and send ButtonEvent
23    public void pressButton( Location location )
24    {
25       pressed = true;
26
27       buttonListener.buttonPressed(
28          new ButtonEvent( this, location ) );
29    }
30
31    // reset Button and send ButtonEvent
32    public void resetButton( Location location )
33    {
34       pressed = false;
```

Fig. H.8 Class **Button**, which represents a **Button** in the model, informs listeners when a **Button** has been pressed or reset (part 1 of 2).

```
35
36          buttonListener.buttonReset(
37             new ButtonEvent( this, location ) );
38       }
39
40       // return whether button is pressed
41       public boolean isButtonPressed()
42       {
43          return pressed;
44       }
45
46       // invoked when Elevator has departed
47       public void elevatorDeparted( ElevatorMoveEvent moveEvent ) {}
48
49       // invoked when Elevator has arrived
50       public void elevatorArrived( ElevatorMoveEvent moveEvent )
51       {
52          resetButton( moveEvent.getLocation() );
53       }
54    }
```

Fig. H.8 Class **Button**, which represents a **Button** in the model, informs listeners when a **Button** has been pressed or reset (part 2 of 2).

Method **pressButton** sends a **buttonPressed** event to the registered **ButtonListener** (line 11), and method **resetButton** sends a **buttonReset** event to the **ButtonListener**. Method **setButtonListener** (lines 17–20) allows an object to receive **ButtonEvent**s by registering itself as the **ButtonListener**.

Line 25 of method **pressButton** sets attribute **pressed** to **true**, and lines 27–28 pass a **ButtonEvent** to method **buttonPressed** of the **buttonListener**. Line 34 of method **resetButton** sets attribute **pressed** to **false** and line 36–37 pass a **ButtonEvent** to method **buttonReset** of the **buttonListener**.

Lastly, according to Fig. H.2, classes **Button** implements interface **ElevatorMoveListener**. Method **elevatorArrived** (lines 50–53) calls method **resetButton** to reset the **Button**.

H.6 Class ElevatorShaft

Class **ElevatorShaft** (Fig. H.9) represents the **ElevatorShaft** in which the **Elevator** travels in the model. Most methods in class **ElevatorShaft** access **private** variables, listen for messages from the **Elevator** and send "bubble up" events to the **ElevatorModel**, which sends them to the **ElevatorView**. According to the class diagram of Fig. 15.21, class **ElevatorShaft** contains one **Elevator** object, two **Button** objects, two **Door** objects and two **Light** objects. The **Button**, **Door** and **Light** objects refer to the buttons, doors and lights on each **Floor**. Line 15 declares the **Elevator** object—**elevator**. Lines 18–19 declare the **Button**s **firstFloorButton** and **secondFloorButton**. Lines 22–23 declare the **Door**s **firstFloorDoor** and **secondFloorDoor**. Lines 26–27 declare the **Light**s **firstFloorLight** and **secondFloorLight**. Lines 169–208 provide methods to access references to these objects.

```
1  // ElevatorShaft.java
2  // Represents elevator shaft, which contains elevator
3  package com.deitel.jhtp4.elevator.model;
4
5  // Java core packages
6  import java.util.*;
7
8  // Deitel packages
9  import com.deitel.jhtp4.elevator.event.*;
10
11 public class ElevatorShaft implements ElevatorMoveListener,
12    LightListener, BellListener {
13
14    // Elevator
15    private Elevator elevator;
16
17    // Buttons on Floors
18    private Button firstFloorButton;
19    private Button secondFloorButton;
20
21    // Doors on Floors
22    private Door firstFloorDoor;
23    private Door secondFloorDoor;
24
25    // Lights on Floors
26    private Light firstFloorLight;
27    private Light secondFloorLight;
28
29    // listeners
30    private DoorListener doorListener;
31    private ButtonListener buttonListener;
32    private LightListener lightListener;
33    private BellListener bellListener;
34    private Set elevatorMoveListeners;
35
36    // constructor initializes aggregated components
37    public ElevatorShaft( Floor firstFloor, Floor secondFloor )
38    {
39       // instantiate Set for ElevatorMoveListeners
40       elevatorMoveListeners = new HashSet( 1 );
41
42       // anonymous inner class listens for ButtonEvents
43       ButtonListener floorButtonListener =
44          new ButtonListener() {
45
46          // called when Floor Button has been pressed
47          public void buttonPressed( ButtonEvent buttonEvent )
48          {
49             // request elevator move to location
50             Location location = buttonEvent.getLocation();
51             buttonListener.buttonPressed( buttonEvent );
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 1 of 6).

```
52             elevator.requestElevator( location );
53          }
54
55          // called when Floor Button has been reset
56          public void buttonReset( ButtonEvent buttonEvent )
57          {
58             buttonListener.buttonReset( buttonEvent );
59          }
60       }; // end anonymous inner class
61
62       // instantiate Floor Buttons
63       firstFloorButton = new Button();
64       secondFloorButton = new Button();
65
66       // register anonymous ButtonListener with Floor Buttons
67       firstFloorButton.setButtonListener(
68          floorButtonListener );
69       secondFloorButton.setButtonListener(
70          floorButtonListener );
71
72       // Floor Buttons listen for ElevatorMoveEvents
73       addElevatorMoveListener( firstFloorButton );
74       addElevatorMoveListener( secondFloorButton );
75
76       // anonymous inner class listens for DoorEvents
77       DoorListener floorDoorListener = new DoorListener() {
78
79          // called when Floor Door has opened
80          public void doorOpened( DoorEvent doorEvent )
81          {
82             // forward event to doorListener
83             doorListener.doorOpened( doorEvent );
84          }
85
86          // called when Floor Door has closed
87          public void doorClosed( DoorEvent doorEvent )
88          {
89             // forward event to doorListener
90             doorListener.doorClosed( doorEvent );
91          }
92       }; // end anonymous inner class
93
94       // instantiate Floor Doors
95       firstFloorDoor = new Door();
96       secondFloorDoor = new Door();
97
98       // register anonymous DoorListener with Floor Doors
99       firstFloorDoor.addDoorListener( floorDoorListener );
100      secondFloorDoor.addDoorListener( floorDoorListener );
101
102      // instantiate Lights, then listen for LightEvents
103      firstFloorLight = new Light();
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 2 of 6).

```
104         addElevatorMoveListener( firstFloorLight );
105         firstFloorLight.setLightListener( this );
106
107         secondFloorLight = new Light();
108         addElevatorMoveListener( secondFloorLight );
109         secondFloorLight.setLightListener( this );
110
111         // instantiate Elevator object
112         elevator = new Elevator( firstFloor, secondFloor );
113
114         // register for ElevatorMoveEvents from elevator
115         elevator.addElevatorMoveListener( this );
116
117         // listen for BellEvents from elevator
118         elevator.setBellListener( this );
119
120         // anonymous inner class listens for ButtonEvents from
121         // elevator
122         elevator.setButtonListener(
123            new ButtonListener() {
124
125               // invoked when button has been pressed
126               public void buttonPressed( ButtonEvent buttonEvent )
127               {
128                  // send event to listener
129                  buttonListener.buttonPressed( buttonEvent );
130               }
131
132               // invoked when button has been reset
133               public void buttonReset( ButtonEvent buttonEvent )
134               {
135                  // send event to listener
136                  buttonListener.buttonReset(
137                     new ButtonEvent( this, elevator ) );
138               }
139            } // end anonymous inner class
140         );
141
142         // anonymous inner class listens for DoorEvents from
143         // elevator
144         elevator.setDoorListener(
145            new DoorListener() {
146
147               // invoked when door has opened
148               public void doorOpened( DoorEvent doorEvent )
149               {
150                  // send event to listener
151                  doorListener.doorOpened( doorEvent );
152               }
153
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 3 of 6).

```
154             // invoked when door has closed
155             public void doorClosed( DoorEvent doorEvent )
156             {
157                // send event to listener
158                doorListener.doorClosed( doorEvent );
159             }
160          } // end anonymous inner class
161       );
162
163       // start Elevator Thread
164       elevator.start();
165
166    } // end ElevatorShaft constructor
167
168    // get Elevator
169    public Elevator getElevator()
170    {
171       return elevator;
172    }
173
174    // get Door on first Floor
175    public Door getFirstFloorDoor()
176    {
177       return firstFloorDoor;
178    }
179
180    // get Door on second Floor
181    public Door getSecondFloorDoor()
182    {
183       return secondFloorDoor;
184    }
185
186    // get Button on first Floor
187    public Button getFirstFloorButton()
188    {
189       return firstFloorButton;
190    }
191
192    // get Button on second Floor
193    public Button getSecondFloorButton()
194    {
195       return secondFloorButton;
196    }
197
198    // get Light on first Floor
199    public Light getFirstFloorLight()
200    {
201       return firstFloorLight;
202    }
203
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 4 of 6).

```
204    // get Light on second Floor
205    public Light getSecondFloorLight()
206    {
207       return secondFloorLight;
208    }
209
210    // invoked when Bell rings
211    public void bellRang( BellEvent bellEvent )
212    {
213       bellListener.bellRang( bellEvent );
214    }
215
216    // invoked when Light turns on
217    public void lightTurnedOn( LightEvent lightEvent )
218    {
219       lightListener.lightTurnedOn( lightEvent );
220    }
221
222    // invoked when Light turns off
223    public void lightTurnedOff( LightEvent lightEvent )
224    {
225       lightListener.lightTurnedOff( lightEvent );
226    }
227
228    // invoked when Elevator departs
229    public void elevatorDeparted( ElevatorMoveEvent moveEvent )
230    {
231       Iterator iterator = elevatorMoveListeners.iterator();
232
233       // iterate Set of ElevatorMoveEvent listeners
234       while ( iterator.hasNext() ) {
235
236          // get respective ElevatorMoveListener from Set
237          ElevatorMoveListener listener =
238             ( ElevatorMoveListener ) iterator.next();
239
240          // send ElevatorMoveEvent to this listener
241          listener.elevatorDeparted( moveEvent );
242       }
243    } // end method elevatorDeparted
244
245    // invoked when Elevator arrives
246    public void elevatorArrived( ElevatorMoveEvent moveEvent )
247    {
248       // obtain iterator from Set
249       Iterator iterator = elevatorMoveListeners.iterator();
250
251       // get next DoorListener
252       while ( iterator.hasNext() ) {
253
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 5 of 6).

```
254           // get next ElevatorMoveListener from Set
255           ElevatorMoveListener listener =
256              ( ElevatorMoveListener ) iterator.next();
257
258           // send ElevatorMoveEvent to this listener
259           listener.elevatorArrived( moveEvent );
260
261        } // end while loop
262     } // end method elevatorArrived
263
264     // set listener to DoorEvents
265     public void setDoorListener( DoorListener listener )
266     {
267        doorListener = listener;
268     }
269
270     // set listener to ButtonEvents
271     public void setButtonListener( ButtonListener listener )
272     {
273        buttonListener = listener;
274     }
275
276     // add listener to ElevatorMoveEvents
277     public void addElevatorMoveListener(
278        ElevatorMoveListener listener )
279     {
280        elevatorMoveListeners.add( listener );
281     }
282
283     // set listener to LightEvents
284     public void setLightListener( LightListener listener )
285     {
286        lightListener = listener;
287     }
288
289     // set listener to BellEvents
290     public void setBellListener( BellListener listener )
291     {
292        bellListener = listener;
293     }
294  }
```

Fig. H.9 Class **ElevatorShaft**, which represents the **ElevatorShaft**, which sends events from the **Elevator** to the **ElevatorModel** (part 6 of 6).

The main responsibility of the **ElevatorShaft** is to receive events from other objects then to send these events to the **ElevatorModel** (the **ElevatorModel** then sends the events to the **ElevatorView**, which displays the workings of the model). The **ElevatorShaft** contains references to several different listener objects, such as a **DoorListener**, a **ButtonListener**, a **LightListener**, a **BellListener** and several **ElevatorMoveListener**s. Lines 30–34 declare these listeners—line 34 declares a **Set** to hold multiple **ElevatorMoveListener**s, because the **Button**s, **Door**s, **Light**s and the **ElevatorModel** are all **ElevatorMoveListener**s. Lines

265–293 provide methods allowing objects to register themselves as listeners for various events.

The constructor (lines 37–166) instantiates listener objects from several inner classes—these listener objects receive events from other objects, then re-send the events to the listener objects defined in line 30–34. For example, lines 43–60 declare a **ButtonListener** object called **floorButtonListener**, which contains the logic for when a **Button** on a **Floor** has been pressed or reset. Lines 63–70 instantiate **firstFloorButton** and **secondFloorButton**, then register **floorButtonListener** as a **ButtonListener** for both **Button** objects. When either **Button** has been pressed, that **Button** invokes method **buttonPressed** (lines 47–53) of the **floorButtonListener**. When either **Button** has been reset, that **Button** invokes the **floorButtonListener**'s method **buttonReset** (lines 56–59). Method **buttonPressed** requests the **Elevator** by invoking the **Elevator**'s method **requestElevator**—method **buttonPressed** passes a **Location** reference of the **Floor** that generated the **ButtonEvent**. Both methods **buttonPressed** and **buttonReset** send the **ButtonEvent** to the **ButtonListener** defined in line 31 (which, in this case, is **ElevatorModel**).

Lines 77–92 declare a **DoorListener** object called **floorDoorListener**, which contains the logic for when a **Door** on a **Floor** has opened or closed. Lines 95–100 instantiate **firstFloorDoor** and **secondFloorDoor**, then register **floorDoorListener** as a **DoorListener** for both **Door** objects. When either **Door** has opened, that **Door** calls method **doorOpened** (lines 80–84) of the **floorDoorListener**. When either **Door** has closed, that **Door** calls method **doorClosed** (lines 87–91) of the **floorDoorListener**. Both methods send the **DoorEvent** to the **DoorListener** declared in line 30 (which, in this case, is **ElevatorModel**).

Lines 112–115 instantiate the **Elevator** and register the **ElevatorShaft** as an **ElevatorMoveListener** with the **Elevator**. When the **Elevator** has departed, the **Elevator** invokes method **elevatorDeparted** (lines 229–243), which informs all objects in **elevatorMoveListeners** of the departure. When the **Elevator** has arrived, the **Elevator** invokes method **elevatorArrived** (lines 246–262), which informs all objects in **elevatorMoveListeners** of the arrival.

H.7 Classes Light and Bell

Class **Light** (Fig. H.10) represents the **Light**s on the **Floor**s in the model. Objects of classes **Light** help decorate the view by sending events to the **ElevatorView** via the "bubble up" technique described previously. In our simulation, the **ElevatorView** turns on and off the **Light** in the view upon receiving a **lightTurnedOn** or **lightTurnedOff** event, respectively.

```
1  // Light.java
2  // Light turns a light on or off
3  package com.deitel.jhtp4.elevator.model;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.event.*;
7
```

Fig. H.10 Class **Light** represents a **Light** on the **Floor** in the model (part 1 of 3).

```
 8  public class Light implements ElevatorMoveListener {
 9
10     // Light state (on/off)
11     private boolean lightOn;
12
13     // time before Light turns off automatically (3 seconds)
14     public static final int AUTOMATIC_TURNOFF_DELAY = 3000;
15
16     // LightListener listens for when Light should turn on/off
17     private LightListener lightListener;
18
19     // location where Light turned on or off
20     private Location lightLocation;
21
22     // set LightListener
23     public void setLightListener( LightListener listener )
24     {
25        lightListener = listener;
26     }
27
28     // turn on Light
29     public void turnOnLight( Location location )
30     {
31        if ( !lightOn ) {
32
33           lightOn = true;
34
35           // send LightEvent to LightListener
36           lightListener.lightTurnedOn(
37              new LightEvent( this, location ) );
38
39           lightLocation = location;
40
41           // declare Thread that ensures automatic Light turn off
42           Thread thread = new Thread(
43              new Runnable() {
44
45                 public void run()
46                 {
47                    // turn off Light if on for more than 3 seconds
48                    try {
49                       Thread.sleep( AUTOMATIC_TURNOFF_DELAY );
50                       turnOffLight( lightLocation );
51                    }
52
53                    // handle exception if interrupted
54                    catch ( InterruptedException exception ) {
55                       exception.printStackTrace();
56                    }
57                 }
58              } // end anonymous inner class
59           );
60
```

Fig. H.10 Class **Light** represents a **Light** on the **Floor** in the model (part 2 of 3).

```
61             thread.start();
62          }
63       } // end method turnOnLight
64
65       // turn off Light
66       public void turnOffLight( Location location )
67       {
68          if ( lightOn ) {
69
70             lightOn = false;
71
72             // send LightEvent to LightListener
73             lightListener.lightTurnedOff(
74                new LightEvent( this, location ) );
75          }
76       } // end method turnOffLight
77
78       // return whether Light is on or off
79       public boolean isLightOn()
80       {
81          return lightOn;
82       }
83
84       // invoked when Elevator has departed
85       public void elevatorDeparted(
86          ElevatorMoveEvent moveEvent )
87       {
88          turnOffLight( moveEvent.getLocation() );
89       }
90
91       // invoked when Elevator has arrived
92       public void elevatorArrived(
93          ElevatorMoveEvent moveEvent )
94       {
95          turnOnLight( moveEvent.getLocation() );
96       }
97    }
```

Fig. H.10 Class **Light** represents a **Light** on the **Floor** in the model (part 3 of 3).

According to Fig. 15.21, class **Light** contains attribute **lightOn** (line 11), which represents the state of the **Light** (on or off). In addition, Fig. 15.21 specifies that class **Light** contains methods **turnOnLight** (lines 29–63) and **turnOffLight** (lines 66–76). Line 33 of method **turnOnLight** sets attribute **lightOn** to **true**, and lines 36–37 call method **lightTurnedOn** of the **lightListener** (line 17). In our model, the **ElevatorShaft** is the **lightListener**—the **ElevatorShaft** receives events from the **Light** and sends them to the **ElevatorModel**, which sends them to the **ElevatorView**. The **ElevatorShaft** uses method **setLightListener** (lines 23–26) to register for **LightEvent**s. Method **turnOffLight** sets attribute **lightOn** to **false**, then calls method **lightTurnedOff** of the **lightListener**.

We decided in Section 15.12 to make class **Light** an active class, so that the **Light** turns itself off after three seconds of being illuminated. Lines 42–59 of method **turnOn-**

Light instantiate a thread that handles this responsibility. Method **run** (lines 45–57) puts this thread to sleep for three seconds, then turns off the **Light**. Line 61 of method **turnOnLight** starts the thread.

According to Fig. H.2, class **Light** implements interface **ElevatorMoveListener**. Lines 85–89 and lines 92–96 list methods **elevatorDeparted** and **elevatorArrived**, respectively. In our model, the **Light** turns off when the **Elevator** has departed, and the **Light** turns on when the **Elevator** has arrived.

Class **Bell** (Fig. H.11) represents the **Bell** in the model and sends a **bellRang** event to a **BellListener** when the **Bell** has rung. This event eventually "bubbles up" to the **ElevatorView**. The **ElevatorView** plays an audio clip of a bell ringing upon receiving a **bellRang** event.

```
1  // Bell.java
2  // Represents Bell in simulation
3  package com.deitel.jhtp4.elevator.model;
4
5  // Deitel packages
6  import com.deitel.jhtp4.elevator.event.*;
7
8  public class Bell implements ElevatorMoveListener {
9
10    // BellListener listens for BellEvent object
11    private BellListener bellListener;
12
13    // ring bell and send BellEvent object to listener
14    private void ringBell( Location location )
15    {
16       if ( bellListener != null )
17          bellListener.bellRang(
18             new BellEvent( this, location ) );
19    }
20
21    // set BellListener
22    public void setBellListener( BellListener listener )
23    {
24       bellListener = listener;
25    }
26
27    // invoked when Elevator has departed
28    public void elevatorDeparted( ElevatorMoveEvent moveEvent ) {}
29
30    // invoked when Elevator has arrived
31    public void elevatorArrived( ElevatorMoveEvent moveEvent )
32    {
33       ringBell( moveEvent.getLocation() );
34    }
35 }
```

Fig. H.11 Class **Bell** represents the **Bell** in the model.

According to Fig. 15.21, class **Bell** does not contain attributes, because the **Bell** does not change state. However, Fig. 15.21 specifies that class **Bell** contains method **ringBell** (lines 14–19), which rings the **Bell** by invoking method **bellRang** of the **BellListener bellListener** (line 11). In our simulation, the **Elevator** is the **bellListener**—the **Elevator** receives event from the **Bell**, then sends the event to the **ElevatorShaft**, which sends the event to the **ElevatorModel**, which sends the event to the **ElevatorView**. The **ElevatorView** then plays an audio clip of a bell ringing. The **Elevator** uses method **setBellListener** (lines 22–24) to register for **BellEvent**s from the **Bell**.

According to Fig. H.2, class **Bell** implements interface **ElevatorMoveListener**. Line 28 and lines 31–34 list methods **elevatorDeparted** and **elevatorArrived**, respectively. In our simulation, the **Bell** rings when the **Elevator** has arrived.

H.8 Class Elevator

Class **Elevator** (Fig. H.12) represents the elevator car that travels between the two **Floor**s in the **ElevatorShaft** while carrying a **Person**. According to the class diagram of Fig. 15.21, class **Elevator** contains one object each of classes **Button**, **Door** and **Bell**—lines 37–39 declare objects **elevatorButton**, **elevatorDoor** and **bell**. As discussed in Section 9.23, class **Elevator** extends superclass **Location**, because the **Elevator** is a location that the **Person** can occupy. Class **Elevator** implements methods **getButton** (lines 232–235) and **getDoor** (lines 238–241) provided by class **Location**. Method **getButton** returns the **elevatorButton** and method **getDoor** returns the **elevatorDoor**. According to Fig. 15.21, we also must include two **Location** objects—one named **currentFloor** (line 22), which represents the current **Floor** being serviced, and the other named **destinationFloor** (line 25), which represents the **Floor** at which the **Elevator** will arrive. In addition, Fig. 15.21 specifies that class **Elevator** requires **boolean** variable **moving** (line 19), which describes whether the **Elevator** is moving or idle, and **boolean** variable **summoned** (line 28), which describes whether the **Elevator** has been summoned. Also, class **Elevator** uses **int** constant **TRAVEL_TIME** (line 44), which indicates the five second travel time between **Floor**s.

```
1  // Elevator.java
2  // Travels between Floors in the ElevatorShaft
3  package com.deitel.jhtp4.elevator.model;
4
5  // Java core packages
6  import java.util.*;
7
8  // Deitel packages
9  import com.deitel.jhtp4.elevator.event.*;
10 import com.deitel.jhtp4.elevator.ElevatorConstants;
11
12 public class Elevator extends Location implements Runnable,
13    BellListener, ElevatorConstants {
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 1 of 9).

```
14
15    // manages Elevator thread
16    private boolean elevatorRunning = false;
17
18    // describes Elevator state (idle or moving)
19    private boolean moving = false;
20
21    // current Floor
22    private Location currentFloorLocation;
23
24    // destination Floor
25    private Location destinationFloorLocation;
26
27    // Elevator needs to service other Floor
28    private boolean summoned;
29
30    // listener objects
31    private Set elevatorMoveListeners;
32    private ButtonListener elevatorButtonListener;
33    private DoorListener elevatorDoorListener;
34    private BellListener bellListener;
35
36    // Door, Button and Bell on Elevator
37    private Door elevatorDoor;
38    private Button elevatorButton;
39    private Bell bell;
40
41    public static final int ONE_SECOND = 1000;
42
43    // time needed to travel between Floors (5 seconds)
44    private static final int TRAVEL_TIME = 5 * ONE_SECOND;
45
46    // max travel time for Elevator (20 minutes)
47    private static final int MAX_TRAVEL_TIME =
48       20 * 60 * ONE_SECOND;
49
50    // Elevator's thread to handle asynchronous movement
51    private Thread thread;
52
53    // constructor creates variables; registers for ButtonEvents
54    public Elevator( Floor firstFloor, Floor secondFloor )
55    {
56       setLocationName( ELEVATOR_NAME );
57
58       // instantiate Elevator's Door, Button and Bell
59       elevatorDoor = new Door();
60       elevatorButton = new Button();
61       bell = new Bell();
62
63       // register Elevator for BellEvents
64       bell.setBellListener( this );
65
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 2 of 9).

```
66          // instantiate listener Set
67          elevatorMoveListeners = new HashSet( 1 );
68
69          // start Elevator on first Floor
70          currentFloorLocation = firstFloor;
71          destinationFloorLocation = secondFloor;
72
73          // register elevatorButton for ElevatorMoveEvents
74          addElevatorMoveListener( elevatorButton );
75
76          // register elevatorDoor for ElevatorMoveEvents
77          addElevatorMoveListener( elevatorDoor );
78
79          // register bell for ElevatorMoveEvents
80          addElevatorMoveListener( bell );
81
82          // anonymous inner class listens for ButtonEvents from
83          // elevatorButton
84          elevatorButton.setButtonListener(
85             new ButtonListener() {
86
87                // invoked when elevatorButton has been pressed
88                public void buttonPressed( ButtonEvent buttonEvent )
89                {
90                   // send ButtonEvent to listener
91                   elevatorButtonListener.buttonPressed(
92                      buttonEvent );
93
94                   // start moving Elevator to destination Floor
95                   setMoving( true );
96                }
97
98                // invoked when elevatorButton has been reset
99                public void buttonReset( ButtonEvent buttonEvent )
100               {
101                  // send ButtonEvent to listener
102                  elevatorButtonListener.buttonReset(
103                     buttonEvent );
104               }
105            } // end anonymous inner class
106         );
107
108         // anonymous inner class listens for DoorEvents from
109         // elevatorDoor
110         elevatorDoor.addDoorListener(
111            new DoorListener() {
112
113               // invoked when elevatorDoor has opened
114               public void doorOpened( DoorEvent doorEvent )
115               {
116                  // get Location associated with DoorEvent
117                  Location location = doorEvent.getLocation();
```

Fig. H.12 Class **`Elevator`** represents the **`Elevator`** traveling between two **`Floor`**s, operating asynchronously with other objects (part 3 of 9).

```
118                String locationName = location.getLocationName();
119
120                // open Door on Floor Location
121                if ( !locationName.equals( ELEVATOR_NAME ) )
122                   location.getDoor().openDoor( location );
123
124                // send DoorEvent to listener
125                elevatorDoorListener.doorOpened( new DoorEvent(
126                   doorEvent.getSource(), Elevator.this ));
127             }
128
129             // invoked when elevatorDoor has closed
130             public void doorClosed( DoorEvent doorEvent )
131             {
132                // get Location associated with DoorEvent
133                Location location = doorEvent.getLocation();
134                String locationName = location.getLocationName();
135
136                // close Door on Floor Location
137                if ( !locationName.equals( ELEVATOR_NAME ) )
138                   location.getDoor().closeDoor( location );
139
140                // send DoorEvent to listener
141                elevatorDoorListener.doorClosed( new DoorEvent(
142                  doorEvent.getSource(), Elevator.this ));
143             }
144          } // end anonymous inner class
145       );
146    } // end Elevator constructor
147
148    // swaps current Floor Location with opposite Floor Location
149    private void changeFloors()
150    {
151       Location location = currentFloorLocation;
152       currentFloorLocation = destinationFloorLocation;
153       destinationFloorLocation = location;
154    }
155
156    // start Elevator thread
157    public void start()
158    {
159       if ( thread == null )
160          thread = new Thread( this );
161
162       elevatorRunning = true;
163       thread.start();
164    }
165
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 4 of 9).

```
166    // stop Elevator thread; method run terminates
167    public void stopElevator()
168    {
169       elevatorRunning = false;
170    }
171
172    // Elevator thread's run method
173    public void run()
174    {
175       while ( isElevatorRunning() ) {
176
177          // remain idle until awoken
178          while ( !isMoving() )
179             pauseThread( 10 );
180
181          // close elevatorDoor
182          getDoor().closeDoor( currentFloorLocation );
183
184          // closing Door takes one second
185          pauseThread( ONE_SECOND );
186
187          // issue elevatorDeparted Event
188          sendDepartureEvent( currentFloorLocation );
189
190          // Elevator needs 5 seconds to travel
191          pauseThread( TRAVEL_TIME );
192
193          // stop Elevator
194          setMoving( false );
195
196          // swap Floor Locations
197          changeFloors();
198
199          // issue elevatorArrived Event
200          sendArrivalEvent( currentFloorLocation );
201
202       } // end while loop
203
204    } // end method run
205
206    // invoked when Person rides Elevator between Floors
207    public synchronized void ride()
208    {
209       try {
210          Thread.sleep( MAX_TRAVEL_TIME );
211       }
212       catch ( InterruptedException exception ) {
213          // method doorOpened in Person interrupts method sleep;
214          // Person has finished riding Elevator
215       }
216    }
217
```

Fig. H.12 Class **`Elevator`** represents the **`Elevator`** traveling between two **`Floor`**s, operating asynchronously with other objects (part 5 of 9).

```
218    // pause concurrent thread for number of milliseconds
219    private void pauseThread( int milliseconds )
220    {
221       try {
222          Thread.sleep( milliseconds );
223       }
224
225       // handle if interrupted while sleeping
226       catch ( InterruptedException exception ) {
227          exception.printStackTrace();
228       }
229    } // end method pauseThread
230
231    // return Button on Elevator
232    public Button getButton()
233    {
234       return elevatorButton;
235    }
236
237    // return Door on Elevator
238    public Door getDoor()
239    {
240       return elevatorDoor;
241    }
242
243    // set if Elevator should move
244    public void setMoving( boolean elevatorMoving )
245    {
246       moving = elevatorMoving;
247    }
248
249    // is Elevator moving?
250    public boolean isMoving()
251    {
252       return moving;
253    }
254
255    // is Elevator thread running?
256    private boolean isElevatorRunning()
257    {
258       return elevatorRunning;
259    }
260
261    // register ElevatorMoveListener for ElevatorMoveEvents
262    public void addElevatorMoveListener(
263       ElevatorMoveListener listener )
264    {
265       elevatorMoveListeners.add( listener );
266    }
267
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 6 of 9).

```
268    // register ButtonListener for ButtonEvents
269    public void setButtonListener( ButtonListener listener )
270    {
271       elevatorButtonListener = listener;
272    }
273
274    // register DoorListener for DoorEvents
275    public void setDoorListener( DoorListener listener )
276    {
277       elevatorDoorListener = listener;
278    }
279
280    // register BellListener fpr BellEvents
281    public void setBellListener( BellListener listener )
282    {
283       bellListener = listener;
284    }
285
286    // notify all ElevatorMoveListeners of arrival
287    private void sendArrivalEvent( Location location )
288    {
289       // obtain iterator from Set
290       Iterator iterator = elevatorMoveListeners.iterator();
291
292       // get next DoorListener
293       while ( iterator.hasNext() ) {
294
295          // get next ElevatorMoveListener from Set
296          ElevatorMoveListener listener =
297             ( ElevatorMoveListener ) iterator.next();
298
299          // send event to listener
300          listener.elevatorArrived( new
301             ElevatorMoveEvent( this, location ) );
302
303       } // end while loop
304
305       // service queued request, if one exists
306       if ( summoned ) {
307          pauseThread( Door.AUTOMATIC_CLOSE_DELAY );
308          setMoving( true ); // start moving Elevator
309       }
310
311       summoned = false; // request has been serviced
312
313    } // end method sendArrivalEvent
314
315    // notify all ElevatorMoveListeners of departure
316    private void sendDepartureEvent( Location location )
317    {
318       // obtain iterator from Set
319       Iterator iterator = elevatorMoveListeners.iterator();
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 7 of 9).

```
320
321         // get next DoorListener
322         while ( iterator.hasNext() ) {
323
324            // get next ElevatorMoveListener from Set
325            ElevatorMoveListener listener =
326               ( ElevatorMoveListener ) iterator.next();
327
328            // send ElevatorMoveEvent to this listener
329            listener.elevatorDeparted( new ElevatorMoveEvent(
330               this, currentFloorLocation ) );
331
332         } // end while loop
333      } // end method sendDepartureEvent
334
335      // request Elevator
336      public void requestElevator( Location location )
337      {
338         // if Elevator is idle
339         if ( !isMoving() ) {
340
341            // if Elevator is on same Floor of request
342            if ( location == currentFloorLocation )
343
344               // Elevator has already arrived; send arrival event
345               sendArrivalEvent( currentFloorLocation );
346
347            // if Elevator is on opposite Floor of request
348            else {
349
350               if ( getDoor().isDoorOpen() )
351                  pauseThread( Door.AUTOMATIC_CLOSE_DELAY );
352               setMoving( true ); // move to other Floor
353            }
354         }
355         else // if Elevator is moving
356
357            // if Elevator departed from same Floor as request
358            if ( location == currentFloorLocation )
359               summoned = true;
360
361            // if Elevator is traveling to Floor of request,
362            // continue traveling
363
364      } // end method requestElevator
365
366      // invoked when bell has rung
367      public void bellRang( BellEvent bellEvent )
368      {
369         // send event to bellListener
370         if ( bellListener != null )
371            bellListener.bellRang( bellEvent );
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 8 of 9).

```
372      }
373   }
```

Fig. H.12 Class **Elevator** represents the **Elevator** traveling between two **Floor**s, operating asynchronously with other objects (part 9 of 9).

According to Fig. H.2, class **Elevator** implements interfaces **ButtonListener**, **DoorListener** and **BellListener** and therefore can listen for **ButtonEvent**s, **DoorEvent**s and **BellEvent**s. Class **Elevator** must send these events to a listener (in this case, the **ElevatorShaft**), so that these events can "bubble up" to the **ElevatorView**. Class **Elevator** contains a **ButtonListener** called **elevatorButtonListener** (line 32), a **DoorListener** called **elevatorDoorListener** (line 33) and a **BellListener** called **bellListener** (line 34). Lines 269–284 list methods **setButtonListener**, **setDoorListener** and **setBellListener** that allow an object—such as **ElevatorShaft**—to register as a listener for these events.

Class **Elevator** contains an anonymous **ButtonListener** (lines 84–106) that registers for **ButtonEvent**s from the **elevatorButton**. When a **Person** has pressed the **elevatorButton**, the **ButtonListener** calls method **buttonPressed** (lines 88–96) of the **ButtonListener**. Lines 91–92 of this method call method **buttonPressed** of the **elevatorButtonListener**, and line 95 informs the **Elevator** to move using method **setMoving**. When the **Button** has been reset, the **ButtonListener** calls method **buttonReset** (lines 99–104) of the **ButtonListener**. Lines 102–103 of this method calls method **buttonReset** of the **elevatorButtonListener**.

Class **Elevator** contains an anonymous **DoorListener** (lines 110–145) that registers for **DoorEvent**s from the **elevatorDoor**. When the **elevatorDoor** has opened, the **DoorListener** calls method **doorOpened** (lines 114–127) of this **DoorListener**. Lines 121–122 open the **Door** on the **Floor** that generated the event, and lines 125–126 call method **doorOpened** of the **elevatorDoorListener**. Method **doorOpened** guarantees that the **Door** on the **Floor** opens before the passenger exits the **Elevator**. When the **elevatorDoor** has closed, the **DoorListener** calls method **doorClosed** (lines 130–143) of the **DoorListener**. Lines 137–138 close the **Door** on the **Floor** that generated the event, and lines 141–142 call method **doorClosed** of the **elevatorDoorListener**.

Class **Elevator** acts as a thread because it implements interface **Runnable**. Method **run** (lines 173–204) handles the travel between **Floor**s. The method begins with the **Elevator** remaining idle in a **while** loop (lines 178–179). The loop exits when method **buttonPressed** in the anonymous **ButtonListener** calls method **setMoving**.

When the **Elevator** exits the loop, the **Elevator** closes the **elevatorDoor** (line 182) then calls **private** method **sendDepartureEvent** (lines 316–333), to inform all listeners—the **elevatorButton**, the **elevatorDoor**, the **bell** and the **ElevatorShaft**—of the **Elevator**'s departure. Class **Elevator** contains **Set elevatorMoveListeners** (line 31), which stores all registered **ElevatorMoveListener**s. Objects wishing to receive **ElevatorMoveEvent**s from the **Elevator** must call method **addElevatorMoveListener** (lines 262–266), which appends that object to **elevatorMoveListeners**. Method **sendDepartureEvent** invokes method **elevatorDeparted** of each listener object in **Set elevatorMoveListeners**.

Line 191 of method **run** allows the **Elevator** to travel to the **Floor** by calling method **pauseThread** (lines 219–229)—this simulates travel by invoking method **sleep** of class **Thread**. The **Elevator** stops moving when its thread awakens after five seconds. Line 197 calls **private** method **changeFloors** (lines 149–154), which swaps **currentFloorLocation** and **destinationFloorLocation**. Line 200 calls **private** method **sendArrivalEvent** (lines 287–313), which invokes method **elevatorArrived** of all listeners in **Set elevatorMoveListeners**. Lines 306–309 of method **sendArrivalEvent** service any queued request (e.g., a **Person** pressed a **Button** on the **Floor** from which the **Elevator** has departed). If a queued request exists, line 308 invokes method **setMoving** to move the **Elevator** to the opposite **Floor**.

Method **requestElevator** (lines 336–364) requests the **Elevator** and generates a queued request. In our model, the **ButtonListener** defined in the inner class of the **ElevatorShaft** calls this method when a **Button** on either **Floor** has been pressed. The activity diagram of Fig. 5.30 specifies the logic for method **requestElevator**. If the **Elevator** is idle and on the same **Floor** as the **Floor** of the request, line 345 calls method **sendArrivalEvent**, because the **Elevator** has already arrived. If the **Elevator** is idle but on the opposite **Floor** from the **Floor** of the request, line 352 moves the **Elevator** to the opposite **Floor**. If the **Elevator** is traveling to the **Floor** that generated the request, the **Elevator** should continue traveling to that **Floor**. If the **Elevator** is traveling away from the **Floor** that generated the request, the **Elevator** must remember to return to that **Floor** (lines 358–359).

Lastly, as mentioned in Section 15.12, class **Elevator** contains **synchronized** method **ride** (lines 207–216). The **Person** calls this method to guarantee exclusivity with the **Elevator**. Method **ride** ensures that two **Person** objects cannot occupy the **Elevator** at the same time. When a **Person** object invokes method **ride**, that **Person** object obtains a monitor on the **Elevator** object. Other objects may not access the **Elevator** until that **Person** releases the monitor by exiting method **ride**.

H.9 Class Person

Class **Person** (Fig. H.13) represents a **Person** that walks across the **Floor**s and rides the **Elevator** in our simulation. According to the class diagram of Fig. 15.21, class **Person** contains one object of class **Location** (line 20) that represents the **Person**'s current location in the model (either on a **Floor** or in the **Elevator**). In addition, Fig. 15.21 specifies that **Person** requires **int** attribute **ID** (line 14) as a unique identifier and **boolean** attribute **moving** (line 17), which indicates whether **Person** is walking across the **Floor** or waiting for a **Door** to open.

```
1  // Person.java
2  // Person riding the elevator
3  package com.deitel.jhtp4.elevator.model;
4
5  // Java core packages
6  import java.util.*;
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 1 of 7).

```
 7
 8  // Deitel packages
 9  import com.deitel.jhtp4.elevator.event.*;
10
11  public class Person extends Thread implements DoorListener {
12
13     // identification number
14     private int ID = -1;
15
16     // represents whether Person is moving or waiting
17     private boolean moving;
18
19     // reference to Location (either on Floor or in Elevator)
20     private Location location;
21
22     // listener object for PersonMoveEvents
23     private PersonMoveListener personMoveListener;
24
25     // time in milliseconds to walk to Button on Floor
26     private static final int TIME_TO_WALK = 3000;
27
28     // maximum time Person will wait for Elevator (10 minutes)
29     private static final int TIME_WAITING = 10 * 60 * 1000;
30
31     // types of messages Person may send
32     public static final int PERSON_CREATED = 1;
33     public static final int PERSON_ARRIVED = 2;
34     public static final int PERSON_ENTERING_ELEVATOR = 3;
35     public static final int PERSON_PRESSING_BUTTON = 4;
36     public static final int PERSON_EXITING_ELEVATOR = 5;
37     public static final int PERSON_EXITED = 6;
38
39     // Person constructor set initial location
40     public Person( int identifier, Location initialLocation )
41     {
42        super();
43
44        ID = identifier; // assign unique identifier
45        location = initialLocation; // set Floor Location
46        moving = true; // start moving toward Button on Floor
47     }
48
49     // set listener for PersonMoveEvents
50     public void setPersonMoveListener(
51        PersonMoveListener listener )
52     {
53        personMoveListener = listener;
54     }
55
56     // invoked when Door has opened
57     public void doorOpened( DoorEvent doorEvent )
58     {
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 2 of 7).

```
59          // set Person on Floor where Door opened
60          setLocation( doorEvent.getLocation() );
61
62          // interrupt Person's sleep method in run method and
63          // Elevator's ride method
64          interrupt();
65       }
66
67       // invoked when Door has closed
68       public void doorClosed( DoorEvent doorEvent ) {}
69
70       // set Person Location
71       private void setLocation( Location newLocation )
72       {
73          location = newLocation;
74       }
75
76       // get current Location
77       private Location getLocation()
78       {
79          return location;
80       }
81
82       // get identifier
83       public int getID()
84       {
85          return ID;
86       }
87
88       // set if Person should move
89       public void setMoving( boolean personMoving )
90       {
91          moving = personMoving;
92       }
93
94       // get if Person should move
95       public boolean isMoving()
96       {
97          return moving;
98       }
99
100      // Person either rides or waits for Elevator
101      public void run()
102      {
103         sendPersonMoveEvent( PERSON_CREATED );
104
105         // walk to Elevator
106         pauseThread( TIME_TO_WALK );
107         setMoving( false );
108
109         // Person arrived at Floor Button
110         sendPersonMoveEvent( PERSON_ARRIVED );
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 3 of 7).

```
111
112         // get current Door on Floor
113         Door currentFloorDoor = location.getDoor();
114
115         // determine if Door on Floor is open
116         try {
117
118            boolean doorOpen = currentFloorDoor.isDoorOpen();
119
120            // if Door on Floor is closed
121            if ( !doorOpen ) {
122
123               // press Floor Button
124               sendPersonMoveEvent( PERSON_PRESSING_BUTTON );
125               pauseThread( 1000 );
126
127               // register for Floor Door's doorOpen event
128               currentFloorDoor.addDoorListener( this );
129
130               // press Floor's Button to request Elevator
131               Button floorButton = getLocation().getButton();
132               floorButton.pressButton( getLocation() );
133
134               // wait for Floor's Door to open
135               sleep( TIME_WAITING );
136
137               // unregister with Floor's Door if too long
138               currentFloorDoor.removeDoorListener( this );
139            }
140
141            // if Door on Floor is open, ride Eelevator
142            else
143               enterAndRideElevator();
144         }
145
146         // handle exception when interrupted from waiting
147         catch ( InterruptedException interruptedException ) {
148
149            // Person unregisters for Floor's Door doorOpen event
150            currentFloorDoor.removeDoorListener( this );
151
152            // enter and ride Elevator when Door on Floor opens,
153            pauseThread( 1000 );
154            enterAndRideElevator();
155         }
156
157         // waiting for Elevator's Door to open takes a second
158         pauseThread( 1000 );
159
160         // begin walking away from Elevator
161         setMoving( true );
162
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 4 of 7).

```
163         // Person exits Elevator
164         sendPersonMoveEvent( PERSON_EXITING_ELEVATOR );
165
166         // walking from elevator takes five seconds
167         pauseThread( 2 * TIME_TO_WALK );
168
169         // Person exits simulation
170         sendPersonMoveEvent( PERSON_EXITED );
171
172      } // end method run
173
174      // Person enters Elevator
175      private void enterAndRideElevator()
176      {
177         // Person enters Elevator
178         sendPersonMoveEvent( PERSON_ENTERING_ELEVATOR );
179
180         // set Person Location to Elevator
181         Floor floorLocation = ( Floor ) getLocation();
182         setLocation(
183            floorLocation.getElevatorShaft().getElevator() );
184
185         // Person takes one second to enter Elevator
186         pauseThread( 1000 );
187
188         // register for Elevator's Door's doorOpen event
189         Door elevatorDoor = getLocation().getDoor();
190         elevatorDoor.addDoorListener( this );
191
192         // pressing Elevator Button takes one second
193         sendPersonMoveEvent( PERSON_PRESSING_BUTTON );
194         pauseThread( 1000 );
195
196         // get Elevator's Button
197         Button elevatorButton = getLocation().getButton();
198
199         // press Elevator's Button
200         elevatorButton.pressButton( location );
201
202         // Door closing takes one second
203         pauseThread( 1000 );
204
205         // ride in Elevator
206         Elevator elevator = ( Elevator ) getLocation();
207         elevator.ride();
208
209         // Person finished riding Elevator
210
211         // unregister for Elevator's Door's doorOpen event
212         elevatorDoor.removeDoorListener( this );
213
214      } // end method enterAndRideElevator
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 5 of 7).

```
215
216    // pause thread for desired number of milliseconds
217    private void pauseThread( int milliseconds )
218    {
219       try {
220          sleep( milliseconds );
221       }
222
223       // handle exception if interrupted when paused
224       catch ( InterruptedException interruptedException ) {
225          interruptedException.printStackTrace();
226       }
227    } // end method pauseThread
228
229    // send PersonMoveEvent to listener, depending on event type
230    private void sendPersonMoveEvent( int eventType )
231    {
232       // create new event
233       PersonMoveEvent event =
234          new PersonMoveEvent( this, getLocation(), getID() );
235
236       // send Event to this listener, depending on eventType
237       switch ( eventType ) {
238
239          // Person has been created
240          case PERSON_CREATED:
241             personMoveListener.personCreated( event );
242             break;
243
244          // Person arrived at Elevator
245          case PERSON_ARRIVED:
246             personMoveListener.personArrived( event );
247             break;
248
249          // Person entered Elevator
250          case PERSON_ENTERING_ELEVATOR:
251             personMoveListener.personEntered( event );
252             break;
253
254          // Person pressed Button object
255          case PERSON_PRESSING_BUTTON:
256             personMoveListener.personPressedButton( event );
257             break;
258
259          // Person exited Elevator
260          case PERSON_EXITING_ELEVATOR:
261             personMoveListener.personDeparted( event );
262             break;
263
264          // Person exited simulation
265          case PERSON_EXITED:
266             personMoveListener.personExited( event );
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 6 of 7).

```
267               break;
268
269            default:
270               break;
271         }
272      } // end method sendPersonMoveEvent
273   }
```

Fig. H.13 Class **Person** represents the **Person** that rides the **Elevator**. The **Person** operates asynchronously with other objects (part 7 of 7).

Class **Person** is subclass of class **Thread**. The **Person** performs all actions, such as walking across **Floor**s and riding the **Elevator**, in method **run** (lines 101–172). Method **run** represents the lifetime of a **Person** described in the sequence diagram of Fig. 15.20. Class **Person** contains a **PersonMoveListener** object (line 23) to which the **Person** sends **PersonMoveEvent**s. In our simulation, the **ElevatorModel** uses method **setPersonMoveListener** (lines 50–54) to register itself as the **PersonMoveListener**. The **ElevatorModel**, upon receiving a **PersonMoveEvent**, sends the event to the **ElevatorView**—therefore, the **ElevatorView** "knows" when a **Person** has performed certain actions discussed momentarily.

There are several types of actions a **Person** performs in its lifetime, so there exists several types of **PersonMoveEvent**s that a **Person** may send to the **personMoveListener**. Lines 32–37 define a series of constants in which each constant represents a unique type of **PersonMoveEvent**. The **Person** sends events to **personMoveListener** when

- the **Person** has been created
- the **Person** arrives at the **Elevator**
- the **Person** enters the **Elevator**
- the **Person** presses a **Button** (either in the **Elevator** or on a **Floor**)
- the **Person** exits the **Elevator**
- the **Person** exits the simulation

When the **Person** decides to send an event to its **PersonMoveListener**, the **Person** calls **private** method **sendPersonMoveEvent** and passes the desired constant as a parameter. This method sends the event associated with the constant. For example, line 124 calls

```
sendPersonMoveEvent( PERSON_PRESSED_BUTTON );
```

when the **Person** presses a **Button** on a **Floor**. In method **run**, the **Person** walks to the **Elevator**, then sends a **personArrived** event upon arrival at the **Elevator**. We use the activity diagram of Fig. 5.29 to determine the **Person**'s next action. If the **Door** on the **Floor** is closed (line 121), the **Person** must wait for that **Door** to open. Specifically, line 128 registers the **Person** as a **DoorListener** for that **Door**, and lines 131–132 allow the **Person** to press the **Button** on that **Floor**. The **Person** waits for the **Door** to open by calling method **sleep** (line 135) of the **Person**'s superclass **Thread**. When the **Door** opens, that **Door** informs **Person** in **doorOpened**

(lines 57–65). Line 64 of method **doorOpened** interrupts the **Person**'s thread, which terminates method **sleep** of line 135. Method **interrupt** throws an **InterruptedException** received by a **catch** block (lines 147–155). Line 150 of this **catch** block unregisters the **Person** with the **Door** on the **Floor**, and line 154 calls **private** method **enterAndRideElevator** (lines 175–214)—however, according to Fig. 5.29, if the **Door** on the **Floor** is already open when the **Person** arrives, the **Person** calls method **enterAndRideElevator** immediately.

Line 178 of method **enterAndRideElevator** sends a **personEntered** event to **personMoveListener**, indicating that the **Person** is entering the **Elevator**. When the **Person** enters the **Elevator**, the **Person**'s **Location** references the **Elevator** (lines 181–183). When the **Person** has entered the **Elevator**, lines 189–190 register the **Person** as a **DoorListener** with the **Door** in the **Elevator**. Lines 197–200 allow the **Person** to press the **Button** in the **Elevator** and to send a **personPressedButton** event to the **personMoveListener**. Lines 206–207 invoke the **synchronized** method **ride** in the **Elevator**, ensuring that other **Person**s cannot occupy the **Elevator**. When the **Elevator** arrives, it sends an **elevatorArrived** event to the **Door** in the **Elevator**, which opens that **Door** and invokes method **doorOpened** of the **Person**. Method **doorOpened**, as previously mentioned, interrupts the **Person**'s thread—in this case, method **interrupt** terminates the sleep in method **ride** and allows the **Person** to exit the **Elevator** (allowing a **Person** waiting for the **Elevator** to enter). Method **enterAndRideElevator** returns, and lines 161–170 of method **run** make the **Person** exit the **Elevator** and exit the simulation shortly thereafter.

H.10 Component Diagrams Revisited

In Section 13.17, we introduced the component diagram for the elevator simulation. In our simulation, the each class in the model imports package **event**—we showed the components of package **event** in Fig. G.15. Figure H.14 presents the component diagram for package **model**. Each component in package **model** maps to a class from the class diagram of Fig. 15.21—package **model** aggregates package **event**.

H.11 Conclusion

This concludes discussion case study model. We hope you have enjoyed the design process of our elevator simulation using the UML, along with the presentation of object-oriented fundamentals and Java-specific topics, such as event handling and multithreading. Using the concepts discussed in this case study, you should now be able to tackle even larger systems. We encourage you to read Appendix I, which implements the **ElevatorView**, which transforms the **ElevatorModel** that we have designed into a vibrant and interactive program abundant with graphics, animation and sound.

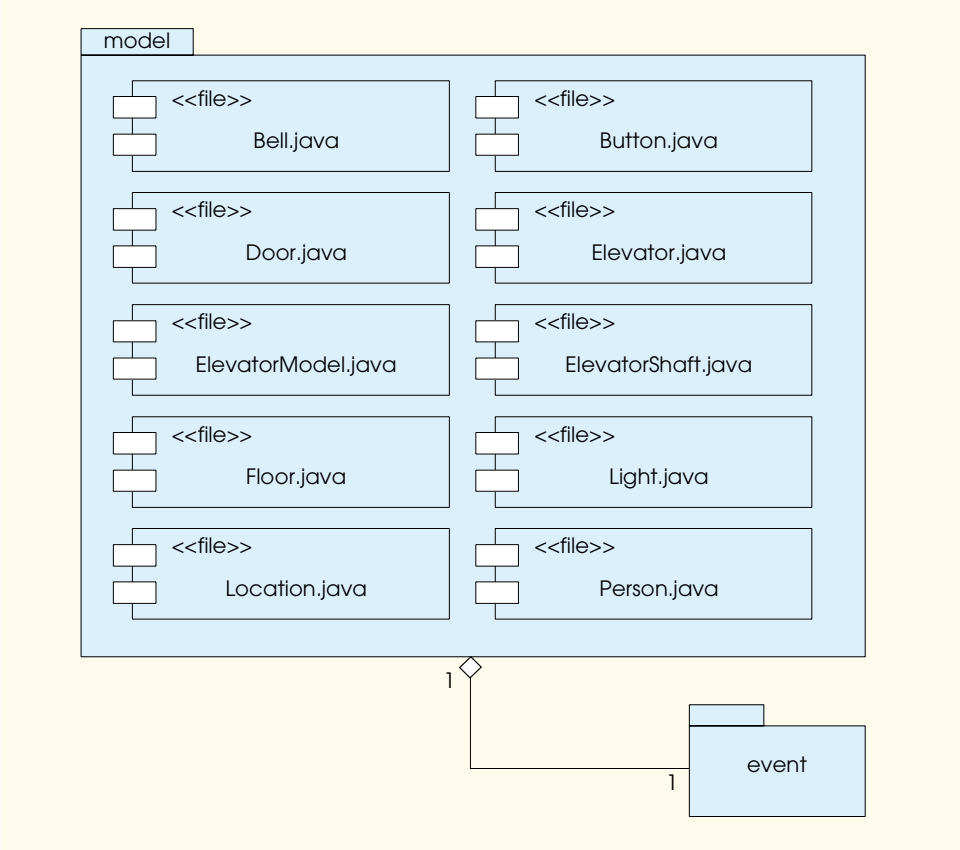


Fig. H.14 Component diagram for package **`model`**.

Elevator View (on CD)

I.1 Introduction

This appendix contains the implementation for class **ElevatorView** (Fig. I.1). Familiarity with the "Thinking About Objects" sections from all chapters (Chapter 22, in particular) necessitates the understanding of material presented in this appendix. Class **ElevatorView** is the largest class in the simulation. To facilitate discussion, we have divided the discussion of the **ElevatorView** into five topics—*Class Objects*, *Class Constants*, *Class Constructor*, *Event Handling* and *Component Diagrams Revisited*.

```
1  // ElevatorView.java
2  // View for ElevatorSimulation
3  package com.deitel.jhtp4.elevator.view;
4
5  // Java core packages
6  import java.awt.*;
7  import java.awt.event.*;
8  import java.util.*;
9  import java.applet.*;
10
11 // Java extension package
12 import javax.swing.*;
13
14 // Deitel packages
15 import com.deitel.jhtp4.elevator.event.*;
16 import com.deitel.jhtp4.elevator.ElevatorConstants;
17
18 public class ElevatorView extends JPanel
19    implements ActionListener, ElevatorModelListener,
20       ElevatorConstants {
21
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 1 of 18).

```
22     // ElevatorView dimensions
23     private static final int VIEW_WIDTH = 800;
24     private static final int VIEW_HEIGHT = 435;
25
26     // offset for positioning Panels in ElevatorView
27     private static final int OFFSET = 10;
28
29     // Elevator repaints components every 50 ms
30     private static final int ANIMATION_DELAY = 50;
31
32     // horizontal distance constants
33     private static final int PERSON_TO_BUTTON_DISTANCE = 400;
34     private static final int BUTTON_TO_ELEVATOR_DISTANCE = 50;
35     private static final int PERSON_TO_ELEVATOR_DISTANCE =
36        PERSON_TO_BUTTON_DISTANCE + BUTTON_TO_ELEVATOR_DISTANCE;
37
38     // times walking to Floor's Button and Elevator
39     private static final int TIME_TO_BUTTON = 3000; // 3 seconds
40     private static final int TIME_TO_ELEVATOR = 1000; // 1 second
41
42     // time traveling in Elevator (5 seconds)
43     private static final int ELEVATOR_TRAVEL_TIME = 5000;
44
45     // Door images for animation
46     private static final String doorFrames[] = {
47        "images/door1.png", "images/door2.png", "images/door3.png",
48        "images/door4.png", "images/door5.png" };
49
50     // Person images for animation
51     private static final String personFrames[] = {
52        "images/bug1.png", "images/bug2.png", "images/bug3.png",
53        "images/bug4.png", "images/bug5.png", "images/bug6.png",
54        "images/bug7.png", "images/bug8.png" };
55
56     // Light images for animation
57     private static final String lightFrames[] = {
58        "images/lightOff.png", "images/lightOn.png" };
59
60     // Floor Light images for animation
61     private static final String firstFloorLightFrames[] = {
62        "images/firstFloorLightOff.png",
63        "images/firstFloorLightOn.png" };
64
65     private static final String secondFloorLightFrames[] = {
66        "images/secondFloorLightOff.png",
67        "images/secondFloorLightOn.png", };
68
69     // Floor Button images for animation
70     private static final String floorButtonFrames[] = {
71        "images/floorButtonUnpressed.png",
72        "images/floorButtonPressed.png",
73        "images/floorButtonLit.png" };
74
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 2 of 18).

```
75     // Elevator Button images for animation
76     private static final String elevatorButtonFrames[] = {
77        "images/elevatorButtonUnpressed.png",
78        "images/elevatorButtonPressed.png",
79        "images/elevatorButtonLit.png" };
80
81     // Bell images for animation
82     private static final String bellFrames[] = {
83        "images/bell1.png", "images/bell2.png",
84        "images/bell3.png" };
85
86     private static final String floorImage =
87        "images/floor.png";
88     private static final String ceilingImage =
89        "images/ceiling.png";
90     private static final String elevatorImage =
91        "images/elevator.png";
92     private static final String wallImage =
93        "images/wall.jpg";
94     private static final String elevatorShaftImage =
95        "images/elevatorShaft.png";
96
97     // audio files
98     private static final String bellSound = "bell.wav";
99     private static final String doorOpenSound = "doorOpen.wav";
100    private static final String doorCloseSound = "doorClose.wav";
101    private static final String elevatorSound = "elevator.au";
102    private static final String buttonSound = "button.wav";
103    private static final String walkingSound = "walk.wav";
104
105    private static final String midiFile = "sounds/liszt.mid";
106
107    // ImagePanels for Floors, ElevatorShaft, wall and ceiling
108    private ImagePanel firstFloorPanel;
109    private ImagePanel secondFloorPanel;
110    private ImagePanel elevatorShaftPanel;
111    private ImagePanel wallPanel;
112    private ImagePanel ceilingPanel;
113
114    // MovingPanels for Elevator
115    private MovingPanel elevatorPanel;
116
117    // AnimatedPanels for Buttons, Bell, Lights and Door
118    private AnimatedPanel firstFloorButtonPanel;
119    private AnimatedPanel secondFloorButtonPanel;
120    private AnimatedPanel elevatorButtonPanel;
121    private AnimatedPanel bellPanel;
122    private AnimatedPanel elevatorLightPanel;
123    private AnimatedPanel firstFloorLightPanel;
124    private AnimatedPanel secondFloorLightPanel;
125    private AnimatedPanel doorPanel;
126
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 3 of 18).

```
127    // List containing AnimatedPanels for all Person objects
128    private java.util.List personAnimatedPanels;
129
130    // AudioClips for sound effects
131    private AudioClip bellClip;
132    private AudioClip doorOpenClip;
133    private AudioClip doorCloseClip;
134    private AudioClip elevatorClip;
135    private AudioClip buttonClip;
136    private AudioClip walkClip;
137
138    // ElevatorMusic to play in Elevator
139    private ElevatorMusic elevatorMusic;
140
141    // Timer for animation controller;
142    private javax.swing.Timer animationTimer;
143
144    // distance from top of screen to display Floors
145    private int firstFloorPosition;
146    private int secondFloorPosition;
147
148    // Elevator's velocity
149    private double elevatorVelocity;
150
151    // ElevatorView constructor
152    public ElevatorView()
153    {
154       // specifiy null Layout
155       super( null );
156
157       instantiatePanels();
158       placePanelsOnView();
159       initializeAudio();
160
161       // calculate distance Elevator travels
162       double floorDistance =
163          firstFloorPosition - secondFloorPosition;
164
165       // calculate time needed for travel
166       double time = ELEVATOR_TRAVEL_TIME / ANIMATION_DELAY;
167
168       // determine Elevator velocity (rate = distance / time)
169       elevatorVelocity = ( floorDistance + OFFSET ) / time;
170
171       // start animation Thread
172       startAnimation();
173
174    } // end ElevatorView constructor
175
176    // instantiate all Panels (Floors, Elevator, etc.)
177    private void instantiatePanels()
178    {
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 4 of 18).

```
179         // instantiate ImagePanels representing Floors
180         firstFloorPanel = new ImagePanel( 0, floorImage );
181         secondFloorPanel = new ImagePanel( 0, floorImage );
182
183         // calculate first and second Floor positions
184         firstFloorPosition =
185            VIEW_HEIGHT - firstFloorPanel.getHeight();
186         secondFloorPosition =
187            ( int ) ( firstFloorPosition / 2 ) - OFFSET;
188
189         firstFloorPanel.setPosition( 0, firstFloorPosition );
190         secondFloorPanel.setPosition( 0, secondFloorPosition );
191
192         wallPanel = new ImagePanel( 0, wallImage );
193
194         // create and position ImagePanel for ElevatorShaft
195         elevatorShaftPanel =
196            new ImagePanel( 0, elevatorShaftImage );
197
198         double xPosition = PERSON_TO_ELEVATOR_DISTANCE + OFFSET;
199         double yPosition =
200            firstFloorPosition - elevatorShaftPanel.getHeight();
201
202         elevatorShaftPanel.setPosition( xPosition, yPosition );
203
204         // create and position ImagePanel for ceiling
205         ceilingPanel = new ImagePanel( 0, ceilingImage );
206
207         yPosition = elevatorShaftPanel.getPosition().getY() -
208            ceilingPanel.getHeight();
209
210         ceilingPanel.setPosition( xPosition, yPosition );
211
212         // create and position MovingPanel for Elevator
213         elevatorPanel = new MovingPanel( 0, elevatorImage );
214
215         yPosition = firstFloorPosition - elevatorPanel.getHeight();
216
217         elevatorPanel.setPosition( xPosition, yPosition );
218
219         // create and position first Floor Button
220         firstFloorButtonPanel =
221            new AnimatedPanel( 0, floorButtonFrames );
222
223         xPosition = PERSON_TO_BUTTON_DISTANCE + 2 * OFFSET;
224         yPosition = firstFloorPosition - 5 * OFFSET;
225         firstFloorButtonPanel.setPosition( xPosition, yPosition );
226
227         int floorButtonPressedFrameOrder[] = { 0, 1, 2 };
228         firstFloorButtonPanel.addFrameSequence(
229            floorButtonPressedFrameOrder );
230
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 5 of 18).

```
231         // create and position second Floor Button
232         secondFloorButtonPanel =
233            new AnimatedPanel( 1, floorButtonFrames );
234
235         xPosition = PERSON_TO_BUTTON_DISTANCE + 2 * OFFSET;
236         yPosition = secondFloorPosition - 5 * OFFSET;
237         secondFloorButtonPanel.setPosition( xPosition, yPosition );
238
239         secondFloorButtonPanel.addFrameSequence(
240            floorButtonPressedFrameOrder );
241
242         // create and position Floor Lights
243         firstFloorLightPanel =
244            new AnimatedPanel( 0, firstFloorLightFrames );
245
246         xPosition = elevatorPanel.getLocation().x - 4 * OFFSET;
247         yPosition =
248            firstFloorButtonPanel.getLocation().y - 10 * OFFSET;
249         firstFloorLightPanel.setPosition( xPosition, yPosition );
250
251         secondFloorLightPanel =
252            new AnimatedPanel( 1, secondFloorLightFrames );
253
254         yPosition =
255            secondFloorButtonPanel.getLocation().y - 10 * OFFSET;
256         secondFloorLightPanel.setPosition( xPosition, yPosition );
257
258         // create and position Door AnimatedPanels
259         doorPanel = new AnimatedPanel( 0, doorFrames );
260         int doorOpenedFrameOrder[] = { 0, 1, 2, 3, 4 };
261         int doorClosedFrameOrder[] = { 4, 3, 2, 1, 0 };
262         doorPanel.addFrameSequence( doorOpenedFrameOrder );
263         doorPanel.addFrameSequence( doorClosedFrameOrder );
264
265         // determine where Door is located relative to Elevator
266         yPosition =
267            elevatorPanel.getHeight() - doorPanel.getHeight();
268
269         doorPanel.setPosition( 0, yPosition );
270
271         // create and position Light AnimatedPanel
272         elevatorLightPanel = new AnimatedPanel( 0, lightFrames );
273         elevatorLightPanel.setPosition( OFFSET, 5 * OFFSET );
274
275         // create and position Bell AnimatedPanel
276         bellPanel = new AnimatedPanel( 0, bellFrames );
277
278         yPosition = elevatorLightPanel.getPosition().getY() +
279            elevatorLightPanel.getHeight() + OFFSET;
280
281         bellPanel.setPosition( OFFSET, yPosition );
282         int bellRingAnimation[] = { 0, 1, 0, 2 };
283         bellPanel.addFrameSequence( bellRingAnimation );
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 6 of 18).

```
284
285       // create and position Elevator's Button AnimatedPanel
286       elevatorButtonPanel =
287          new AnimatedPanel( 0, elevatorButtonFrames );
288
289       yPosition = elevatorPanel.getHeight() - 6 * OFFSET;
290       elevatorButtonPanel.setPosition( 10 * OFFSET, yPosition );
291
292       int buttonPressedFrameOrder[] = { 0, 1, 2 };
293       elevatorButtonPanel.addFrameSequence(
294          buttonPressedFrameOrder );
295
296       // create List to store Person AnimatedPanels
297       personAnimatedPanels = new ArrayList();
298
299    } // end method instantiatePanels
300
301    // place all Panels on ElevatorView
302    private void placePanelsOnView()
303    {
304       // add Panels to ElevatorView
305       add( firstFloorPanel );
306       add( secondFloorPanel );
307       add( ceilingPanel );
308       add( elevatorPanel );
309       add( firstFloorButtonPanel );
310       add( secondFloorButtonPanel );
311       add( firstFloorLightPanel );
312       add( secondFloorLightPanel );
313       add( elevatorShaftPanel );
314       add( wallPanel );
315
316       // add Panels to Elevator's MovingPanel
317       elevatorPanel.add( doorPanel );
318       elevatorPanel.add( elevatorLightPanel );
319       elevatorPanel.add( bellPanel );
320       elevatorPanel.add( elevatorButtonPanel );
321
322    } // end method placePanelsOnView
323
324    // get sound effects and elevatorMusic
325    private void initializeAudio()
326    {
327       // create AudioClip sound effects from audio files
328       SoundEffects sounds = new SoundEffects();
329       sounds.setPathPrefix( "sounds/" );
330
331       bellClip = sounds.getAudioClip( bellSound );
332       doorOpenClip = sounds.getAudioClip( doorOpenSound );
333       doorCloseClip = sounds.getAudioClip( doorCloseSound );
334       elevatorClip = sounds.getAudioClip( elevatorSound );
335       buttonClip = sounds.getAudioClip( buttonSound );
336       walkClip = sounds.getAudioClip( walkingSound );
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 7 of 18).

```
337
338        // create MIDI player using Java Media Framework
339        elevatorMusic = new ElevatorMusic( midiFile );
340        elevatorMusic.open();
341
342     } // end method initializeAudio
343
344     // starts animation by repeatedly drawing images to screen
345     public void startAnimation()
346     {
347        if ( animationTimer == null ) {
348           animationTimer =
349              new javax.swing.Timer( ANIMATION_DELAY, this );
350           animationTimer.start();
351        }
352        else
353
354           if ( !animationTimer.isRunning() )
355              animationTimer.restart();
356     }
357
358     // stop animation
359     public void stopAnimation()
360     {
361        animationTimer.stop();
362     }
363
364     // update AnimatedPanels animation in response to Timer
365     public void actionPerformed( ActionEvent actionEvent )
366     {
367        elevatorPanel.animate();
368
369        firstFloorButtonPanel.animate();
370        secondFloorButtonPanel.animate();
371
372        Iterator iterator = getPersonAnimatedPanelsIterator();
373
374        while ( iterator.hasNext() ) {
375
376           // get Person's AnimatedPanel from Set
377           AnimatedPanel personPanel =
378              ( AnimatedPanel ) iterator.next();
379
380           personPanel.animate(); // update panel
381        }
382
383        repaint(); // paint all Components
384
385     } // end method actionPerformed
386
387     private Iterator getPersonAnimatedPanelsIterator()
388     {
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 8 of 18).

```
389         // obtain iterator from List
390         synchronized( personAnimatedPanels )
391         {
392            return new ArrayList( personAnimatedPanels ).iterator();
393         }
394      }
395
396      // stop sound clip of Person walking
397      private void stopWalkingSound()
398      {
399         // stop playing walking sound
400         walkClip.stop();
401
402         Iterator iterator = getPersonAnimatedPanelsIterator();
403
404         // but if Person is still walking, then keep playing
405         while ( iterator.hasNext() ) {
406            AnimatedPanel panel = ( AnimatedPanel ) iterator.next();
407
408            if ( panel.getXVelocity() != 0 )
409               walkClip.loop();
410         }
411      } // end method stopWalkingSound
412
413      // returns Person AnimatedPanel with proper identifier
414      private AnimatedPanel getPersonPanel( PersonMoveEvent event )
415      {
416         Iterator iterator = getPersonAnimatedPanelsIterator();
417
418         while ( iterator.hasNext() ) {
419
420            // get next AnimatedPanel
421            AnimatedPanel personPanel =
422               ( AnimatedPanel ) iterator.next();
423
424            // return AnimatedPanel with identifier that matches
425            if ( personPanel.getID() == event.getID() )
426               return personPanel;
427         }
428
429         // return null if no match with correct identifier
430         return null;
431
432      } // end method getPersonPanel
433
434      // invoked when Elevator has departed from Floor
435      public void elevatorDeparted( ElevatorMoveEvent moveEvent )
436      {
437         String location =
438            moveEvent.getLocation().getLocationName();
439
440         // determine if Person is on Elevator
441         Iterator iterator = getPersonAnimatedPanelsIterator();
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 9 of 18).

```
442
443       while ( iterator.hasNext() ) {
444
445          AnimatedPanel personPanel =
446             ( AnimatedPanel ) iterator.next();
447
448          double yPosition = personPanel.getPosition().getY();
449          String panelLocation;
450
451          // determine on which Floor the Person entered
452          if ( yPosition > secondFloorPosition )
453             panelLocation = FIRST_FLOOR_NAME;
454          else
455             panelLocation = SECOND_FLOOR_NAME;
456
457          int xPosition =
458             ( int ) personPanel.getPosition().getX();
459
460          // if Person is inside Elevator
461          if ( panelLocation.equals( location )
462             && xPosition > PERSON_TO_BUTTON_DISTANCE + OFFSET ) {
463
464             // remove Person AnimatedPanel from ElevatorView
465             remove( personPanel );
466
467             // add Person AnimatedPanel to Elevator
468             elevatorPanel.add( personPanel, 1 );
469             personPanel.setLocation( 2 * OFFSET, 9 * OFFSET );
470             personPanel.setMoving( false );
471             personPanel.setAnimating( false );
472             personPanel.setVelocity( 0, 0 );
473             personPanel.setCurrentFrame( 1 );
474          }
475       } // end while loop
476
477       // determine Elevator velocity depending on Floor
478       if ( location.equals( FIRST_FLOOR_NAME ) )
479          elevatorPanel.setVelocity( 0, -elevatorVelocity );
480       else
481
482          if ( location.equals( SECOND_FLOOR_NAME ) )
483             elevatorPanel.setVelocity( 0, elevatorVelocity );
484
485       // begin moving Elevator and play Elevator music
486       elevatorPanel.setMoving( true );
487
488       if ( elevatorClip != null )
489          elevatorClip.play();
490
491       elevatorMusic.play();
492
493    } // end method elevatorDeparted
494
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 10 of 18).

```
495    // invoked when Elevator has arrived at destination Floor
496    public void elevatorArrived( ElevatorMoveEvent moveEvent )
497    {
498       // stop Elevator and music
499       elevatorPanel.setMoving( false );
500       elevatorMusic.getSequencer().stop();
501
502       double xPosition = elevatorPanel.getPosition().getX();
503       double yPosition;
504
505       // set Elevator's position to either first or second Floor
506       if ( elevatorPanel.getYVelocity() < 0 )
507          yPosition =
508             secondFloorPosition - elevatorPanel.getHeight();
509       else
510          yPosition =
511             firstFloorPosition - elevatorPanel.getHeight();
512
513       elevatorPanel.setPosition( xPosition, yPosition );
514
515    } // end method elevatorArrived
516
517    // invoked when Person has been created in model
518    public void personCreated( PersonMoveEvent personEvent )
519    {
520       int personID = personEvent.getID();
521
522       String floorLocation =
523          personEvent.getLocation().getLocationName();
524
525       // create AnimatedPanel representing Person
526       AnimatedPanel personPanel =
527          new AnimatedPanel( personID, personFrames );
528
529       // determine where Person should be drawn initially
530       // negative xPosition ensures Person drawn offscreen
531       double xPosition = - personPanel.getWidth();
532       double yPosition = 0;
533
534       if ( floorLocation.equals( FIRST_FLOOR_NAME ) )
535          yPosition = firstFloorPosition +
536             ( firstFloorPanel.getHeight() / 2 );
537       else
538
539          if ( floorLocation.equals( SECOND_FLOOR_NAME ) )
540             yPosition = secondFloorPosition +
541                ( secondFloorPanel.getHeight() / 2 );
542
543       yPosition -= personPanel.getHeight();
544
545       personPanel.setPosition( xPosition, yPosition );
546
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 11 of 18).

```
547         // add some animations for each Person
548         int walkFrameOrder[] = { 1, 0, 1, 2 };
549         int pressButtonFrameOrder[] = { 1, 3, 3, 4, 4, 1 };
550         int walkAwayFrameOrder[] = { 6, 5, 6, 7 };
551         personPanel.addFrameSequence( walkFrameOrder );
552         personPanel.addFrameSequence( pressButtonFrameOrder );
553         personPanel.addFrameSequence( walkAwayFrameOrder );
554
555         // have Person begin walking to Elevator
556         personPanel.playAnimation( 0 );
557         personPanel.setLoop( true );
558         personPanel.setAnimating( true );
559         personPanel.setMoving( true );
560
561         // determine Person velocity
562         double time =
563            ( double ) ( TIME_TO_BUTTON / ANIMATION_DELAY );
564
565         double xDistance = PERSON_TO_BUTTON_DISTANCE -
566            2 * OFFSET + personPanel.getSize().width;
567         double xVelocity = xDistance / time;
568
569         personPanel.setVelocity( xVelocity, 0 );
570         personPanel.setAnimationRate( 1 );
571
572         walkClip.loop(); // play sound clip of Person walking
573
574         // store in personAnimatedPanels
575         synchronized( personAnimatedPanels )
576         {
577            personAnimatedPanels.add( personPanel );
578         }
579
580         add( personPanel, 0 );
581
582      } // end method personCreated
583
584      // invoked when Person has arrived at Elevator
585      public void personArrived( PersonMoveEvent personEvent )
586      {
587         // find Panel associated with Person that issued event
588         AnimatedPanel panel = getPersonPanel( personEvent );
589
590         if ( panel != null ) { // if Person exists
591
592            // Person stops at Floor Button
593            panel.setMoving( false );
594            panel.setAnimating( false );
595            panel.setCurrentFrame( 1 );
596            stopWalkingSound();
597
598            double xPosition = PERSON_TO_BUTTON_DISTANCE -
599               ( panel.getSize().width / 2 );
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 12 of 18).

```
600            double yPosition = panel.getPosition().getY();
601
602            panel.setPosition( xPosition, yPosition );
603         }
604      } // end method personArrived
605
606      // invoked when Person has pressed Button
607      public void personPressedButton( PersonMoveEvent personEvent )
608      {
609         // find Panel associated with Person that issued event
610         AnimatedPanel panel = getPersonPanel( personEvent );
611
612         if ( panel != null ) { // if Person exists
613
614            // Person stops walking and presses Button
615            panel.setLoop( false );
616            panel.playAnimation( 1 );
617
618            panel.setVelocity( 0, 0 );
619            panel.setMoving( false );
620            panel.setAnimating( true );
621            stopWalkingSound();
622         }
623      } // end method personPressedButton
624
625      // invoked when Person has started to enter Elevator
626      public void personEntered( PersonMoveEvent personEvent )
627      {
628         // find Panel associated with Person that issued event
629         AnimatedPanel panel = getPersonPanel( personEvent );
630
631         if ( panel != null ) {
632
633            // determine velocity
634            double time = TIME_TO_ELEVATOR / ANIMATION_DELAY;
635
636            double distance =
637               elevatorPanel.getPosition().getX() -
638               panel.getPosition().getX() + 2 * OFFSET;
639
640            panel.setVelocity( distance / time, -1.5 );
641
642            // Person starts walking
643            panel.setMoving( true );
644            panel.playAnimation( 0 );
645            panel.setLoop( true );
646         }
647      } // end method personEntered
648
649      // invoked when Person has departed from Elevator
650      public void personDeparted( PersonMoveEvent personEvent)
651      {
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 13 of 18).

```
652         // find Panel associated with Person that issued event
653         AnimatedPanel panel = getPersonPanel( personEvent );
654
655         if ( panel != null ) { // if Person exists
656
657            // determine velocity (in opposite direction)
658            double time = TIME_TO_BUTTON / ANIMATION_DELAY;
659            double xVelocity = - PERSON_TO_BUTTON_DISTANCE / time;
660
661            panel.setVelocity( xVelocity, 0 );
662
663            // remove Person from Elevator
664            elevatorPanel.remove( panel );
665
666            double xPosition =
667               PERSON_TO_ELEVATOR_DISTANCE + 3 * OFFSET;
668            double yPosition = 0;
669
670            String floorLocation =
671               personEvent.getLocation().getLocationName();
672
673            // determine Floor onto which Person exits
674            if ( floorLocation.equals( FIRST_FLOOR_NAME ) )
675               yPosition = firstFloorPosition +
676                  ( firstFloorPanel.getHeight() / 2 );
677            else
678
679               if ( floorLocation.equals( SECOND_FLOOR_NAME ) )
680                  yPosition = secondFloorPosition +
681                     ( secondFloorPanel.getHeight() / 2 );
682
683            yPosition -= panel.getHeight();
684
685            panel.setPosition( xPosition, yPosition );
686
687            // add Person to ElevatorView
688            add( panel, 0 );
689
690            // Person starts walking
691            panel.setMoving( true );
692            panel.setAnimating( true );
693            panel.playAnimation( 2 );
694            panel.setLoop( true );
695            walkClip.loop();
696         }
697      } // end method PersonDeparted
698
699      // invoked when Person has exited simulation
700      public void personExited( PersonMoveEvent personEvent)
701      {
702         // find Panel associated with Person that issued moveEvent
703         AnimatedPanel panel = getPersonPanel( personEvent );
704
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 14 of 18).

```
705         if ( panel != null ) { // if Person exists
706
707            panel.setMoving( false );
708            panel.setAnimating( false );
709
710            // remove Person permanently and stop walking sound
711            synchronized( personAnimatedPanels )
712            {
713               personAnimatedPanels.remove( panel );
714            }
715            remove( panel );
716            stopWalkingSound();
717         }
718      } // end method personExited
719
720      // invoked when Door has opened in model
721      public void doorOpened( DoorEvent doorEvent )
722      {
723         // get DoorEvent Location
724         String location =
725            doorEvent.getLocation().getLocationName();
726
727         // play animation of Door opening
728         doorPanel.playAnimation( 0 );
729         doorPanel.setAnimationRate( 2 );
730         doorPanel.setDisplayLastFrame( true );
731
732         // play sound clip of Door opening
733         if ( doorOpenClip != null )
734            doorOpenClip.play();
735
736      } // end method doorOpened
737
738      // invoked when Door has closed in model
739      public void doorClosed( DoorEvent doorEvent )
740      {
741         // get DoorEvent Location
742         String location =
743            doorEvent.getLocation().getLocationName();
744
745         // play animation of Door closing
746         doorPanel.playAnimation( 1 );
747         doorPanel.setAnimationRate( 2 );
748         doorPanel.setDisplayLastFrame( true );
749
750         // play sound clip of Door closing
751         if ( doorCloseClip != null )
752            doorCloseClip.play();
753
754      } // end method doorClosed
755
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 15 of 18).

```
756    // invoked when Button has been pressed in model
757    public void buttonPressed( ButtonEvent buttonEvent )
758    {
759       // get ButtonEvent Location
760       String location =
761          buttonEvent.getLocation().getLocationName();
762
763       // press Elevator Button if from Elevator
764       if ( location.equals( ELEVATOR_NAME ) ) {
765          elevatorButtonPanel.playAnimation( 0 );
766          elevatorButtonPanel.setDisplayLastFrame( true );
767       }
768
769       // press Floor Button if from Floor
770       else
771
772          if ( location.equals( FIRST_FLOOR_NAME ) ) {
773             firstFloorButtonPanel.playAnimation( 0 );
774             firstFloorButtonPanel.setDisplayLastFrame( true );
775          }
776       else
777
778          if ( location.equals( SECOND_FLOOR_NAME ) ) {
779             secondFloorButtonPanel.playAnimation( 0 );
780             secondFloorButtonPanel.setDisplayLastFrame( true );
781          }
782
783       if ( buttonClip != null )
784          buttonClip.play(); // play button press sound clip
785
786    } // end method buttonPressed
787
788    // invoked when Button has been reset in model
789    public void buttonReset( ButtonEvent buttonEvent )
790    {
791       // get ButtonEvent Location
792       String location =
793          buttonEvent.getLocation().getLocationName();
794
795       // reset Elevator Button if from Elevator
796       if ( location.equals( ELEVATOR_NAME ) ) {
797
798          // return to first frame if still animating
799          if ( elevatorButtonPanel.isAnimating() )
800             elevatorButtonPanel.setDisplayLastFrame( false );
801          else
802             elevatorButtonPanel.setCurrentFrame( 0 );
803       }
804
805       // reset Floor Button if from Floor
806       else
807
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 16 of 18).

```
808          if ( location.equals( FIRST_FLOOR_NAME ) ) {
809
810             // return to first frame if still animating
811             if ( firstFloorButtonPanel.isAnimating() )
812                firstFloorButtonPanel.setDisplayLastFrame(
813                   false );
814             else
815                firstFloorButtonPanel.setCurrentFrame( 0 );
816          }
817       else
818
819          if ( location.equals( SECOND_FLOOR_NAME ) ) {
820
821             // return to first frame if still animating
822             if ( secondFloorButtonPanel.isAnimating() )
823                secondFloorButtonPanel.setDisplayLastFrame(
824                   false );
825             else
826                secondFloorButtonPanel.setCurrentFrame( 0 );
827          }
828
829    } // end method buttonReset
830
831    // invoked when Bell has rung in model
832    public void bellRang( BellEvent bellEvent )
833    {
834       bellPanel.playAnimation( 0 ); // animate Bell
835
836       if ( bellClip != null ) // play Bell sound clip
837          bellClip.play();
838    }
839
840    // invoked when Light turned on in model
841    public void lightTurnedOn( LightEvent lightEvent )
842    {
843       // turn on Light in Elevator
844       elevatorLightPanel.setCurrentFrame( 1 );
845
846       String location =
847          lightEvent.getLocation().getLocationName();
848
849       // turn on Light on either first or second Floor
850       if ( location.equals( FIRST_FLOOR_NAME ) )
851          firstFloorLightPanel.setCurrentFrame( 1 );
852
853       else
854
855          if ( location.equals( SECOND_FLOOR_NAME ) )
856             secondFloorLightPanel.setCurrentFrame( 1 );
857
858    } // end method lightTurnedOn
859
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 17 of 18).

```
860     // invoked when Light turned off in model
861     public void lightTurnedOff( LightEvent lightEvent )
862     {
863        // turn off Light in Elevator
864        elevatorLightPanel.setCurrentFrame( 0 );
865
866        String location =
867           lightEvent.getLocation().getLocationName();
868
869        // turn off Light on either first or second Floor
870        if ( location.equals( FIRST_FLOOR_NAME ) )
871           firstFloorLightPanel.setCurrentFrame( 0 );
872
873        else
874
875           if ( location.equals( SECOND_FLOOR_NAME ) )
876              secondFloorLightPanel.setCurrentFrame( 0 );
877
878     } // end method lightTurnedOff
879
880     // return preferred size of ElevatorView
881     public Dimension getPreferredSize()
882     {
883        return new Dimension( VIEW_WIDTH, VIEW_HEIGHT );
884     }
885
886     // return minimum size of ElevatorView
887     public Dimension getMinimumSize()
888     {
889        return getPreferredSize();
890     }
891
892        // return maximum size of ElevatorView
893     public Dimension getMaximumSize()
894     {
895        return getPreferredSize();
896     }
897  }
```

Fig. I.1 **ElevatorView** displays the elevator simulation model (part 18 of 18).

I.2 Class Objects

The **ElevatorView** is a **JPanel** with a series of other **JPanel** "children" added to it. Each **JPanel** provides a visual representation of an object from the model. For example, the **ElevatorView** contains **ImagePanel**s, **MovingPanel**s and **AnimatedPanel**s to represent the **Elevator**, **Person**s, the **ElevatorShaft**, the **Button**s on the **Floor**s, the **Button** in the **Elevator**, the **Door**s on the **Floor**s, the **Door** in the **Elevator**, the **Light**s on the **Floor**s, the two **Floor**s and the **Bell**. Figure I.2 lists the **ElevatorView**'s objects and their counterparts in the model.

The object (in model) of Class...	is represented by the object (in view)...	of Class...
Floor	**firstFloorPanel** **secondFloorPanel**	**ImagePanel** **ImagePanel**
ElevatorShaft	**elevatorShaftPanel**	**ImagePanel**
Elevator	**elevatorPanel**	**MovingPanel**
Button (on **Floor**)	**firstFloorButtonPanel** **secondFloorButtonPanel**	**AnimatedPanel** **AnimatedPanel**
Button (in **Elevator**)	**elevatorButtonPanel**	**AnimatedPanel**
Bell	**bellPanel**	**AnimatedPanel**
Light	**firstFloorLightPanel** **secondFloorLightPanel**	**AnimatedPanel** **AnimatedPanel**
Door (in **Elevator**)	**doorPanel**	**AnimatedPanel**
Door (on **Floor**)	<not represented>	<not represented>
Person	**personAnimatedPanels**	**List** (of **AnimatedPanel**s)

Fig. I.2 Objects in the **ElevatorView** representing objects in the model.

Lines 108–128 of class **ElevatorView** declare the objects in the second column of Fig. I.2. The **firstFloorPanel** (line 108), **secondFloorPanel** (line 109) and **elevatorShaftPanel** (line 110) are **ImagePanel**s, because neither the **Floor**s nor the **ElevatorShaft** move in the simulation. The **elevatorPanel** (line 115) is a **MovingPanel**, because the **Elevator**'s only function is to move between **Floor**s. The **firstFloorButtonPanel** (line 118), **secondFloorButtonPanel** (line 119) and **elevatorButtonPanel** (line 120) are **AnimatedPanel**s, because each object animates when the associated **Button** in the model is pressed or reset. The **bellPanel** (line 121) is an **AnimatedPanel** to animate the ringing of the **Bell**. The **firstFloorLightPanel** (line 123) and **secondFloorLightPanel** (line 124) are **AnimatedPanel**s, because these objects animate when the associated **Light** turns on or off. The **doorPanel** (line 125) is an **AnimatedPanel** to animate the opening and closing of the **Door**. Note that the **ElevatorView** shows only the **Door** in the **Elevator**. The **ElevatorView** does not show the **Door**s on the **Floor**s, which enables us to show the **Elevator**'s interior (these **Door**s would obstruct the objects inside the **Elevator**). Lastly, the **personAnimatedPanels** (line 128) is a **List** of **AnimatedPanel**s, because there can exist several **Person** objects during execution—the **ElevatorView** must need to store dynamically the **AnimatedPanel**s associated with **Person**s in the model.

We add to the **ElevatorView** three more elements that we assume to be parts of the **Elevator** (Fig. I.3), although the model does not represent these elements—a light inside the **Elevator** of type **AnimatedPanel** called **elevatorLightPanel** (line 122), a ceiling over the **Elevator** of type **ImagePanel** called **ceilingPanel** (line 112), and wallpaper inside the building of type **ImagePanel** called **wallPanel** (line 111).

The object (in model) of Class...	is represented by the object (in view)...	of Class...
<not represented>	`elevatorLightPanel`	`AnimatedPanel`
<not represented>	`ceilingPanel`	`ImagePanel`
<not represented>	`wallPanel`	`ImagePanel`

Fig. I.3 Objects in the **`ElevatorView`** not represented in the model.

In addition, the class diagram of Fig. 22.9 shows that the **`ElevatorView`** contains one instance each of classes **`SoundEffects`** and **`ElevatorMusic`**. The **`SoundEffects`** object generates the **`AudioClip`**s used to play sound effects, such as the **`Door`** opening and a **`Person`** walking. Lines 131–136 declare all **`AudioClip`**s, line 139 declares the **`ElevatorMusic`** object, and line 328 (in method **`initializeAudio`**, which we discuss later in this section) declares the **`SoundEffects`** object.

I.3 Class Constants

The **`ElevatorView`** uses constants to specify or obtain such information as

- The initial placement of objects in the **`ElevatorView`**
- The rate at which the **`ElevatorView`** redraws the screen (animation rate)
- The names of image files used by the **`ImagePanel`**s
- The names of sound files used by the **`SoundEffects`** object and the **`ElevatorMusic`**
- The distances in pixels the **`ImagePanel`**s representing the **`Elevator`** and **`Person`** must travel
- The times needed to travel these distances

Lines 23–24 declare **`int`** constants **`VIEW_WIDTH`** and **`VIEW_HEIGHT`**, which specify the **`ElevatorView`**'s dimensions. Method **`getPreferredSize`** (lines 881–884) returns this dimension. Method **`pack`** of class **`ElevatorSimulation`** uses this method to obtain the **`ElevatorView`**'s dimension to place the **`ElevatorView`** in the GUI properly.

The **`ElevatorView`** has a **`null`** layout, so we may place **`ImagePanel`**s in any *x*-*y* coordinate in the **`ElevatorView`**. Line 27 of class **`ElevatorView`** declares **`int`** constant **`OFFSET`**, which helps to determine the exact positions of objects in the **`ElevatorView`**. Line 30 declares **`int`** constant **`ANIMATION_DELAY`**, which specifies the number of milliseconds between animation frames. In our simulation, we initialize **`ANIMATION_DELAY`** to **`50`** milliseconds. Lines 46–95 declare **`String`** constants specifying the image files used to instantiate the **`ImagePanel`**s. Lines 98–105 declare the **`String`** constant specifying the audio files used to instantiate the **`AudioClip`**s and the **`ElevatorMusic`**.

Line 33 declares the **`int`** constant **`PERSON_TO_BUTTON_DISTANCE`**, which represents the horizontal distance between the on-screen location of the **`firstFloorBut-`**

tonPanel or **secondFloorButtonPanel** and the initial on-screen location of an **AnimatedPanel** associated with **Person**. This **AnimatedPanel** uses this constant to calculate the travel distance to the **firstFloorButtonPanel** or **secondFloorButtonPanel**. The **firstFloorButtonPanel** and **secondFloorButtonPanel** use the constant to position themselves on screen. Line 34 declares the **int** constant **BUTTON_TO_ELEVATOR_DISTANCE**, describing the horizontal distance between the **firstFloorButtonPanel** or **secondFloorButtonPanel** and the **elevatorPanel**. The **AnimatedPanel** associated with a **Person** uses this constant to determine the travel distance when entering the **elevatorPanel**.

Line 39 declares **int** constant **TIME_TO_BUTTON**, which represents this **AnimatedPanel**'s travel time to the **firstFloorButtonPanel** or **secondFloorButtonPanel**. Line 40 declares **int** constant **TIME_TO_ELEVATOR**, which represents the time the **AnimatedPanel** associated with a **Person** needs to enter the **elevatorPanel** from the **firstFloorButtonPanel** or **secondFloorButtonPanel**. Using the equation *rate* = *distance* / *time*, the **AnimatedPanel** associated with the **Person** can determine the velocity needed to travel. Similarly, line 43 declares **int** constant **ELEVATOR_TRAVEL_TIME**, which represents the **elevatorPanel**'s travel time between the **firstFloorPanel** and **secondFloorPanel**—lines 166–169 use this constant to determine **double** attribute **elevatorVelocity** (line 149).

I.4 Class constructor

The responsibilities of the **ElevatorView** constructor (lines 152–174) are

- To instantiate all **ImagePanel**s
- To add all **ImagePanel**s to the **ElevatorView**
- To initialize the audio objects
- To compute the **elevatorPanel**'s initial velocity and distance traveled
- To start the animation **Timer**

Lines 157 calls **private** method **instantiatePanels** (lines 177–299), which instantiates all **ImagePanel**s in the **ElevatorView**. Lines 180–181 instantiate the **firstFloorPanel** and **secondFloorPanel**, and lines 184–190 set these objects' positions—the **ElevatorView** positions the **firstFloorPanel** on the bottom of the screen and positions the **secondFloorPanel** in the vertical center of the screen. Line 192 instantiates the **wallPanel ImagePanel**. The **ElevatorView** does not need to calculate the position for the **wallPanel**, because the **wallPanel**'s default screen position (i.e., **xPosition** = **0**, **yPosition** = **0**) is correct. Lines 195–202 and lines 205–210 instantiate and position the **elevatorShaftPanel** and **ceilingPanel ImagePanel**s, respectively. The **ElevatorView** positions the **elevatorShaftPanel** in the right of the screen and positions the **ceilingPanel** above the **elevatorShaftPanel**. Lines 213–217 instantiate the **elevatorPanel** and position it over the **elevatorShaftPanel** above the **firstFloorPanel**. Lines 220–229 instantiate the **firstFloorButtonPanel AnimatedPanel**, place it next to the **elevatorShaftPanel**, then create a frame sequence **Button** pressed animation. Lines 232–240 perform the same actions on the **secondFloorButtonPanel**. Lines 243–249 instantiate the **firstFloorLightPanel AnimatedPanel** and place it to

the left of the **elevatorShaftPanel** but above the **firstFloorButtonPanel**. Lines 251–256 position the **secondFloorLightPanel** above the **secondFloorButtonPanel**. Lines 259–269 instantiate the **doorPanel AnimatedPanel**, place it relative to the **elevatorPanel**'s position (because the **elevatorPanel** will contain the **doorPanel**) and assign frame sequences describing the **Door** animation opening and closing. Lines 272–273 instantiate the **elevatorLightPanel AnimatedPanel** and position it over the **elevatorPanel** and to the left of the **doorPanel**. Lines 276–283 instantiate the **bellPanel**, position it below the **elevatorLightPanel**, then assign a frame sequence describing the **Bell** ringing animation. Lines 286–294 instantiate the **elevatorButtonPanel**, position it in the center of the **elevatorPanel** and assign a frame sequence describing the **Button** pressed animation. Lastly, line 297 instantiates the **ArrayList** holding the **AnimatedPanel**s associated with the **Person**s in the model.

After the **ElevatorView** constructor has called method **instantiatePanels**, the constructor calls method **placePanelsOnView** (lines 302–322), which adds all instantiated **Panel**s to the **ElevatorView**. Lines 317–320 add the **doorPanel**, **elevatorLightPanel**, **bellPanel** and **elevatorButtonPanel** to the **elevatorPanel**. The **ElevatorView** constructor then calls method **initializeAudio** (lines 325–342). Lines 328–329 instantiate a **SoundEffects** object, and lines 331–336 use method **getAudioClip** of the **SoundEffects** object to return the **AudioClip**s for the simulation. Method **play** of class **AudioClip** plays the **AudioClip**—the **ElevatorView** uses this method for sounds that do not repeat, such as the **Bell** ring. Method **loop** of class **AudioClip** plays the clip continually—the **ElevatorView** uses this method for sounds that repeat, such as the sound of footsteps. Lines 339–340 instantiate the **ElevatorMusic** object and ensure that the **MIDI** data is valid.

Finally, lines 162–163 (in the **ElevatorView** constructor) calculate the distance between the two **Floor**s (i.e., the distance the **elevatorPanel** will travel). Lines 166–169 use the equation *rate* = *distance* / *time* to determine the **elevatorPanel**'s velocity when traveling. Finally, line 172 calls method **startAnimation**, which starts the animation timer.

The **ElevatorView** animates the **ImagePanel**s using **animationTimer** (line 142), an instance of class **javax.swing.Timer**. The **animationTimer** starts in the **ElevatorView** constructor through method **startAnimation** (lines 345–356). Class **ElevatorView** implements interface **ActionListener** to listen for **ActionEvent**s. The **animationTimer** sends an **ActionEvent** to the **ElevatorView** every **50** (**ANIMATION_DELAY**) milliseconds. When the **ElevatorView** receives an **ActionEvent**, the **ElevatorView** calls method **actionPerformed** (lines 365–385). Line 367 in this method update the position and current image of the **elevatorPanel** and of the **elevatorPanel**'s children. Lines 369–370 allow the **firstFloorButtonPanel** and **secondFloorButtonPanel** to update themselves. Lines 374–381 iterate **List personAnimatedPanels** and update the position and current image of each **AnimatedPanel** associated with a **Person** in the model. Lastly, line 383 calls method **repaint** to redraw all **ImagePanel**s added to the **ElevatorView** on screen.

We present an object diagram that lists all objects in the **ElevatorView**. Recall that an object diagram provides a snapshot of the structure when the system is running. The object diagram of Fig. I.4 represents the **ElevatorView** after invoking the constructor.

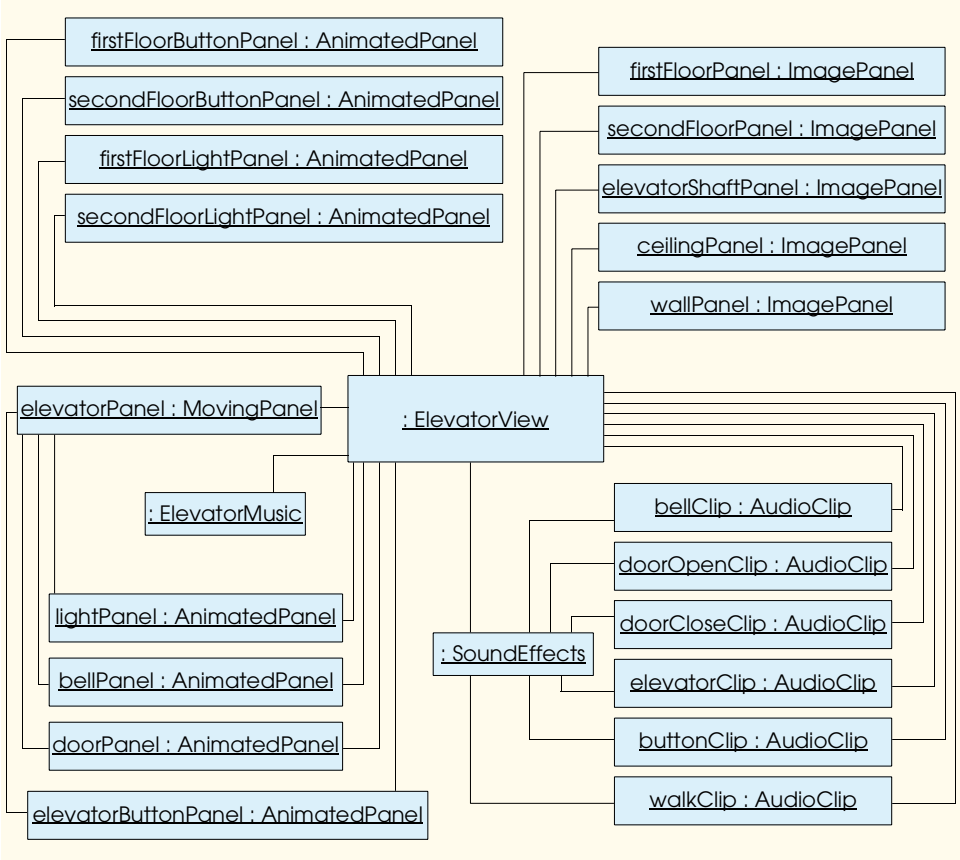


Fig. I.4 Object diagram for the **`ElevatorView`** after initialization.

The **`ElevatorView`** object links (contains an association) with all objects presented in Fig. I.4. The **`elevatorPanel`** links with objects **`elevatorLightPanel`**, **`bellPanel`**, **`doorPanel`** and **`elevatorButtonPanel`**. This association provides a visualization of what is happening in the model—the **`Elevator`** contains a **`Light`**, **`Bell`**, **`Door`** and **`Button`**. The **`SoundEffects`** object links with the **`AudioClip`** objects, because the **`SoundEffects`** object generates the **`AudioClip`** objects.

I.5 Event Handling

Figure 13.19 specified that the **`ElevatorView`** implements interface **`ElevatorModelListener`**, which implements all interfaces in the simulation. The **`ElevatorSimulation`** registers the **`ElevatorView`** as a listener for events from the **`ElevatorModel`**; in other words, the **`ElevatorModel`** sends all events generated in the model to the **`ElevatorView`**.

Every method implementing an interface receives an event object of type **`ElevatorModelEvent`** (or a subclass) as a parameter. For example, the **`doorOpened`** method

receives a **DoorEvent**. Appendix G contains further reference on events and listeners. The following sections discuss the types of events that the **ElevatorView** handles.

I.5.1 ElevatorMoveEvent types

The **ElevatorModel** sends an **ElevatorMoveEvent** when the **Elevator** has either departed or arrived in the model. The **ElevatorModel** invokes method **elevatorDeparted** (lines 435–493) when the **Elevator** has departed from a **Floor**. Lines 441–475 determine if an **AnimatedPanel** associated with a **Person** overlaps the **elevatorPanel** by iterating **personAnimatedPanels** and testing whether any **AnimatedPanel** in the **List** has an on-screen *x*-coordinate greater than that of the **elevatorPanel**. If this is the case, then the **Person** is inside the **Elevator**, and lines 465–468 add the **AnimatedPanel** associated with that **Person** to the **elevatorPanel**. Regardless of whether a **Person** is inside the **Elevator**, lines 478–515 set the **elevatorPanel**'s velocity according to the direction the **Elevator** must travel. Line 500 plays the **elevatorMusic**.

The **ElevatorModel** invokes method **elevatorArrived** (lines 496–515) when the **Elevator** has arrived at a **Floor**. Line 499 stops the **elevatorPanel**, and line 512 stops the **elevatorMusic**. Lines 506–513 change the direction of the **elevatorPanel** for the next travel.

I.5.2 PersonMoveEvent types

The **ElevatorModel** sends a **PersonMoveEvent** when a **Person** has performed some action in the model that the **ElevatorView** must represent. The **ElevatorModel** invokes method **personCreated** (lines 518–582) when the model instantiates a new **Person**. Lines 526–527 instantiate an **AnimatedPanel** for a **Person**. Lines 531–545 determine on which **Floor** to situate the **AnimatedPanel**, depending on the **Floor** on which the event was generated. Lines 548–553 add frame sequences to the **AnimatedPanel** describing the **Person** walking and pressing a **Button**. Lines 556–572 animate the **Person** walking, determine the **Person**'s velocity necessary to reach the **Button** on the **Floor** and play the sound effect of footsteps. Lastly, lines 575–580 add the **AnimatedPanel** associated with the **Person** to **List personAnimatedPanels**, using a **synchronized** block (lines 575–578) to guarantee no other object can access the **List**.

The **ElevatorModel** invokes method **personArrived** (lines 585–604) when a **Person** has arrived at the **Elevator**. Line 588 calls method **getPersonPanel** (lines 414–432), which determines the **AnimatedPanel** associated with the **Person** that issued the event. Specifically, method **getPersonPanel** iterates **List personAnimatedPanels** and returns the **AnimatedPanel** whose identifier matches the identifier of the **PersonMoveEvent**. Lines 590–603 in method **personArrived** stop this **AnimatedPanel** from moving. Line 596 stops the sound of footsteps by calling method **stopWalkingSound** (lines 397–411), which stops the **AudioClip** playing the footstep sound only if no **Person**s are walking.

The **ElevatorModel** invokes method **personPressedButton** (lines 607–623) when a **Person** pressed a **Button**. Line 610 determines the **AnimatedPanel** associated with the **Person** who pressed the **Button**. Line 616 calls method **playAnimation**, which plays the animation sequence of that **Person** pressing the **Button**.

The **ElevatorModel** invokes method **personEntered** (lines 626–647) when a **Person** is about to enter the **Elevator**. Line 629 retrieves the **AnimatedPanel** associated with the **Person** entering the **Elevator**. Line 634–640 determine the velocity needed to walk into the **Elevator**. Line 643–645 animate this **AnimatedPanel** to walk in the **elevatorPanel**.

The **ElevatorModel** invokes method **personDeparted** (lines 650–697) when a **Person** is about to exit the **Elevator**. Line 653 determines the **AnimatedPanel** associated with the **Person** departing from the **Elevator**. Lines 658–661 determine that **Person**'s velocity needed to walk to across the **Floor** to exit the simulation. Lines 664–688 position the **AnimatedPanel** associated with the **Person** on the **Floor** in front of the **Elevator** by removing the **AnimatedPanel** from the **elevatorPanel** and adding the **AnimatedPanel** to the **ElevatorView**. Lines 691–695 animate this **AnimatedPanel** to walk across either the **firstFloorPanel** or **secondFloorPanel** and start the sound of footsteps.

The **ElevatorModel** invokes method **personExited** (lines 700–718) when a **Person** has exited from the simulation. Line 703 determines the **AnimatedPanel** associated with the **Person** who exited the simulation. Lines 711–716 remove the **AnimatedPanel** associated with that **Person** from the **ElevatorView** and stop the sound of footsteps.

I.5.3 DoorEvent types

The **ElevatorModel** sends a **DoorEvent** to the **ElevatorView** when a **Door** has opened or closed in the model. The **ElevatorModel** invokes method **doorOpened** (lines 721–736) when a **Door** has opened. Lines 724–730 animate the **doorPanel** opening, and lines 733–734 plays the **doorOpenClip**, which is the sound effect associated with the **Door**'s opening.

The **ElevatorModel** invokes method **doorClosed** (lines 739–754) when a **Door** has closed. Lines 742–748 animate the **doorPanel** closing, and lines 751–752 plays the **doorClosedClip**, which is the sound effect associated with the **Door**'s closing.

I.5.4 ButtonEvent types

The **ElevatorModel** sends a **ButtonEvent** to the **ElevatorView** when a **Button** has been pressed or reset in the model. The **ElevatorModel** invokes method **buttonPressed** (lines 757–786) when a **Button** has been pressed. Lines 760–761 determine the **Location** where the **Button** was pressed. If the **Location** is the **Elevator**, then lines 764–767 play the **Button** pressed animation inside the **Elevator**. If the **Location** is the first **Floor**, then lines 772–767 play the **Button** pressed animation on the first **Floor**. If the **Location** is the second **Floor**, then lines 778–781 play the **Button** pressed animation on the second **Floor** being pressed. Lines 783–784 play the **buttonClip**, which is the sound effect associated with the **Button** being pressed.

The **ElevatorModel** invokes method **buttonReset** (lines 789–829) when a **Button** has been reset. Lines 792–793 determine the **Location** where the **Button** was reset. If the **Location** is the **Elevator**, then lines 796–803 change the **elevatorButtonPanel**'s image to that of the **Button** reset. If the **Location** is the first **Floor**, then lines 808–816 change the **firstFloorButtonPanel**'s image associated with the

Button reset. If the **Location** is the second **Floor**, then lines 819–827 change the **secondFloorButtonPanel**'s image associated with the **Button** reset.

I.5.5 BellEvent types

The **ElevatorModel** sends a **BellEvent** to the **ElevatorView** by invoking method **bellRang** (lines 832–838) when a **Bell** has rung in the model. Line 834 animates the **bellPanel**, and lines 836–837 play the **bellClip**, which is the sound effect associated with the **Bell** ringing.

I.5.6 LightEvent types

The **ElevatorModel** sends a **LightEvent** to the **ElevatorView** when a **Light** has changed state in the model. The **ElevatorModel** invokes method **lightTurnedOn** (lines 841–858) when a **Light** has turned on. Line 844 turns on **elevatorLightPanel**. Lines 846–856 determine on which **Floor** the **Light** has turned on, then illuminates the **AnimatedPanel** associated with that **Light** in the **ElevatorView**.

The **ElevatorModel** invokes method **lightTurnedOff** (lines 861–878) when a **Light** has turned off. Line 864 turns on **elevatorLightPanel**. Lines 866–876 determine on which **Floor** the **Light** has turned on, then turns off the **AnimatedPanel** associated with that **Light** in the **ElevatorView**.

I.6 Component Diagrams Revisited

In Section 13.17, we introduced the component diagram for the elevator simulation, and in Appendix G and Appendix H, we added components to packages **event** and **model**, respectively. Figure I.5 presents the component diagram for package **view**, which contains components **ElevatorView.java**, **ImagePanel.java**, **MovingPanel.java**, **AnimatedPanel.java**, **ElevatorMusic.java** and **SoundEffects.java**. **ElevatorView.java** aggregates packages **images**, **sounds** and **event**. Packages **images** and **sounds** contain all image files and sound files (components) used by **ElevatorView.java**, respectively. The diagram does not show the components of these directories, because there exist far to many graphics and audio files to represent on one page—the contents of these packages can be found in the directory structures

```
com/deitel/jhtp4/elevator/view/images
com/deitel/jhtp4/elevator/view/sounds
```

(i.e., in the **images** and **sounds** directory where the classes for the view are located in the file system).

I.7 Conclusion

Congratulations! You have completed an "industrial-strength" OOD/UML case study. You are well prepared to tackle more substantial design problems and to go on to deeper study of OOD with the UML. Hopefully you have developed a greater appreciation and understanding of design and implementation processes. Now, you can use Java to implement substantial object-oriented system designs generated by the UML. We hope you have

enjoyed using Java and the UML to construct this case study while learning what features the two technologies have to offer. In addition, we hope you have enjoyed using Java's GUI, graphics and sound capabilities, while learning important object-oriented and Java-related concepts, such as classes, objects, GUI construction, inheritance, event handling and multithreading.

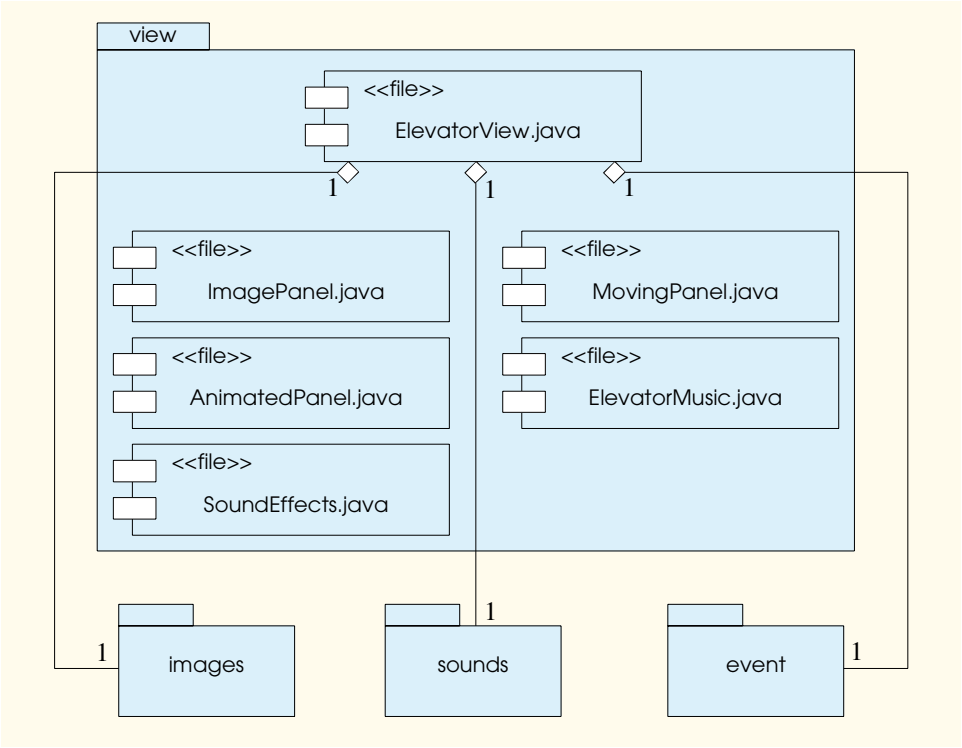


Fig. I.5 Component diagram for package view.

9

Career Opportunities (on CD)

Objectives

- To explore the various online career services.
- To examine the advantages and disadvantages of posting and finding jobs online.
- To review the major online career services Web sites available to job seekers.
- To explore the various online services available to employers seeking to build their workforces.

What is the city but the people?
William Shakespeare

A great city is that which has the greatest men and women, If it be a few ragged huts it is still the greatest city in the whole world.
Walt Whitman

To understand the true quality of people, you must look into their minds, and examine their pursuits and aversions.
Marcus Aurelius

The soul is made for action, and cannot rest till it be employed. Idleness is its rust. Unless it will up and think and taste and see, all is in vain.
Thomas Traherne

Outline

J.1 Introduction
J.2 Resources for the Job Seeker
J.3 Online Opportunities for Employers
J.3.1 Posting Jobs Online
J.3.2 Problems with Recruiting on the Web
J.3.3 Diversity in the Workplace
J.4 Recruiting Services
J.4.1 Testing Potential Employees Online
J.5 Career Sites
J.5.1 Comprehensive Career Sites
J.5.2 Technical Positions
J.5.3 Wireless Positions
J.5.4 Contracting Online
J.5.5 Executive Positions
J.5.6 Students and Young Professionals
J.5.7 Other Online Career Services
J.6 Internet and World Wide Web Resources

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises • Works Cited

J.1 Introduction

There are approximately 40,000 career-advancement services on the Internet today.[1] These services include large, comprehensive job sites, such as **`Monster.com`** (see the upcoming **`Monster.com`** feature), as well as interest-specific job sites such as **`JustJava-Jobs.com`**. Companies can reduce the amount of time spent searching for qualified employees by building a recruiting feature on their sites or establishing an account with a career site. This results in a larger pool of qualified applicants, as online services can automatically select and reject resumes based on user-designated criteria. Online interviews, testing services and other resources also expedite the recruiting process.

Applying for a position online is a relatively new method of exploring career opportunities. Online recruiting services streamline the process and allow job seekers to concentrate their energies in careers that are of interest to them. Job seekers can explore opportunities according to geographic location, position, salary or benefits packages.

Job seekers can learn how to write a resume and cover letter, post them online and search through job listings to find the jobs that best suit their needs. *Entry-level positions*, or positions commonly sought by individuals who are entering a specific field or the job market for the first time; contracting positions; executive-level positions and middle-management-level positions are all available on the Web.

Job seekers will find a number of time-saving features when searching for a job online. These include storing and distributing resumes digitally, e-mail notification of possible positions, salary and relocation calculators, job coaches, self-assessment tools and information on continuing education.

In this appendix, we explore online career services from the employer and employee's perspective. We suggest sites on which applications can be submitted, jobs can be searched for and applicants can be reviewed. We also review services that build recruiting pages directly into an e-business.

J.2 Resources for the Job Seeker

Finding a job online can greatly reduce the amount of time spent applying for a position. Instead of searching through newspapers and mailing resumes, job seekers can request a specific position in a specific industry through a search engine. Some sites allow job seekers to setup intelligent agents to find jobs that meet their requirements. Intelligent agents are programs that search and arrange large amounts of data, and report answers based on that data. When the agent finds a potential match, it sends it to the job seeker's inbox. Resumes can be stored digitally, customized quickly to meet job requirements and e-mailed instantaneously. Potential candidates can also learn more about a company by visiting its Web site. Most employment sites are free to job seekers. These sites typically generate their revenues by charging employers for posting job opportunities and by selling advertising space on their Web pages (see the **Monster.com** feature).

Career services, such as **FlipDog.com**, search a list of employer job sites to find positions. By searching links to employer Web sites, **FlipDog.com** is able to identify positions from companies of all sizes. This feature enables job seekers to find jobs that employers may not have posted outside the corporation's Web site.

Monster.com

Super Bowl ads and effective marketing have made **Monster.com** one of the most recognizable online brands (see Fig. B.1). In fact, in the 24 hours following Super Bowl XXXIV, 5 million job searches occurred on **Monster.com**.[2] The site allows people looking for jobs to post their resumes, search job listings, read advice and information about the job-search process and take proactive steps to improve their careers. These services are free to job seekers. Employers can post job listings, search resume databases and become featured employers.

Posting a resume at **Monster.com** is simple and free. **Monster.com** has a resume builder that allows users to post a resume to its site in 15–30 minutes. Each user can store up to 5 resumes and cover letters on the **Monster.com** server. Some companies offer their employment applications directly through the **Monster.com** site. **Monster.com** has job postings in every state and all major categories. Users can limit access to their personal identification information. As one of the leading recruiting sites on the Web, **Monster.com** is a good place to begin a job search or to find out more about the search process.

Monster.com (Cont.)

Fig. J.1 The **Monster.com** home page. (Courtesy of **Monster.com**.)

Job seekers can visit **FlipDog.com** and choose, by state, the area in which they are looking for a position. Applicants can also conduct worldwide searches. After a user selects a region, **FlipDog.com** requests the user to specify a job category containing several specific positions. The user's choice causes a list of local employers to appear. The user can choose a specific employer or request that **FlipDog.com** search the employment databases for jobs offered by all employers (see Fig. B.2).

Other services, such as employment networks, also help job seekers in their search. Sites such as **Vault.com** (see the **Vault.com** feature) and **WetFeet.com** allow job seekers to post questions about employers and positions in designated chat rooms and on bulletin boards.

J.3 Online Opportunities for Employers

Recruiting on the Internet provides several benefits over traditional recruiting. For example, Web recruiting reaches a much larger audience than posting an advertisement in a local newspaper. Given the breadth of the services provided by most online career services Web sites, the cost of posting online can be considerably less expensive than posting positions through traditional means. Even newspapers, which depend greatly on career opportunity advertising, are starting online career sites.[3]

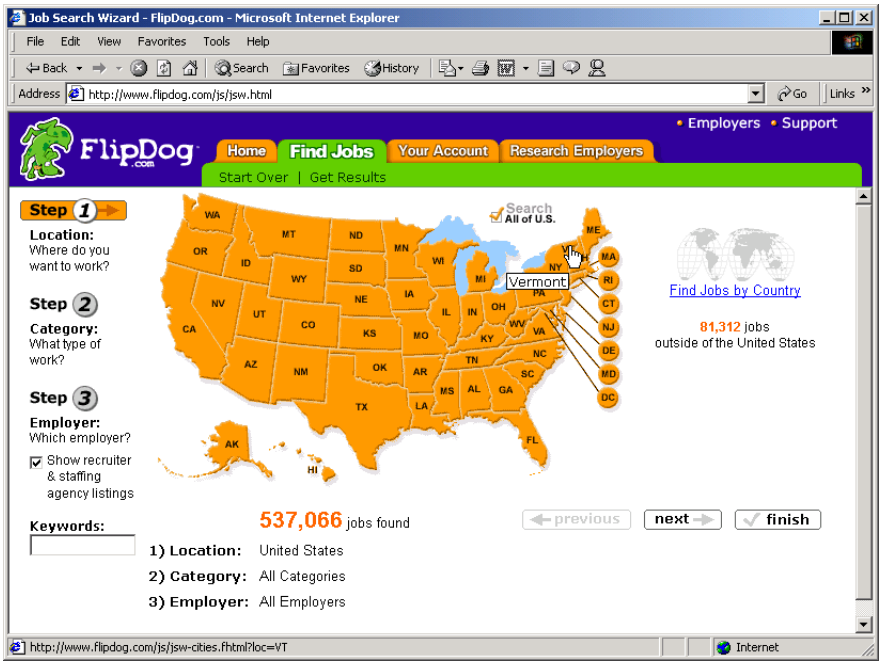


Fig. J.2 **FlipDog.com** job search. (Courtesy of **Flipdog.com**.)

Vault.com: Finding the Right Job on the Web[4]

Vault.com allows potential employees to seek out additional, third-party information for over 3000 companies. By visiting the *Insider Research* page, Web users have access to a profile on the company of their choice, as long as it exists in **Vault.com**'s database. In addition to **Vault.com**'s profile, there is a link to additional commentary by company employees. Most often anonymous, these messages can provide prospective employees with potentially valuable decision-making information. However, users must consider the integrity of the source. For example, a disgruntled employee may leave a posting that is not an accurate representation of the corporate culture of his or her company.

The **Vault.com** *Electronic Watercooler*™ is a message board that allows visitors to post stories, questions and concerns and to advise employees and job seekers. In addition, the site provides e-newsletters and feature stories designed to help job seekers in their search. Individuals seeking information on business, law and graduate schools can also find information on **Vault.com**.

Job-posting and career-advancement services for the job seeker are featured on **Vault.com**. These services include *VaultMatch*, a career service that e-mails job postings as requested, and *Salary Wizard*™, which helps job seekers determine the salary they are worth. Online guides with advice for fulfilling career ambitions are also available.

Vault.com: Finding the Right Job on the Web[4] (Cont.)

Employers can also use the site. *HR Vault*, a feature of **Vault.com**, provides employers with a free job-posting site. It offers career-management advice, employer-to-employee relationship management and recruiting resources.

e-Fact J.1

According to Forrester Research, 33 percent of today's average company's hiring budget goes toward online career services, while the remaining 66 percent is used toward traditional recruiting mechanisms. Online use is expected to increase to 42 percent by 2004, while traditional mechanisms may be reduced to 10 percent.[5]

Generally, jobs posted online are viewed by a larger number of job seekers than jobs posted through traditional means. However, it is important not to overlook the benefits of combining online efforts with human-to-human interaction. There are many job seekers who are not yet comfortable with the process of finding a job online. Often, online recruiting is used as a means of freeing up a recruiter's time for the interviewing process and final selection.

e-Fact J.2

Cisco Systems cites a 39 percent reduction in cost-per-hire expenses, and a 60 percent reduction in the time spent hiring.[6]

J.3.1 Posting Jobs Online

When searching for job candidates online, there are many things employers need to consider. The Internet is a valuable tool for recruiting, but one that takes careful planning to acquire the best results. It provides a good supplementary tool, but should not be considered the complete solution for filling positions. Web sites, such as WebHire (**www.webhire.com**), enhance a company's online employment search (see the WebHire feature).

There are a variety of sites that allow employers to post jobs online. Some of these sites require a fee, which generally runs between $100–200. Postings typically remain on the Web site for 30–60 days. Employers should be careful to post to sites that are most likely to be visited by eligible candidates. As we discovered in the previous section, there are a variety of online career services focused on specific industries, and many of the larger, more comprehensive sites have categorized their databases by job category.

When designing a posting, the recruiter should consider the vast number of postings already on the Web. Defining what makes the job position unique, including information such as benefits and salary, might convince a qualified candidate to further investigate the position (see Fig. B.3).[7]

HotJobs.com career postings are cross-listed on a variety of other sites, thus increasing the number of potential employees who see the job listings. Like **Monster.com** and **jobfind.com**, **hotjobs.com** requires a fee per listing. Employers also have the option of becoming **HotJob.com** members. Employers can gain access to HotJob's *Private Label Job Board*s (private corporate employment sites), online recruiting technology and online career fairs.

WebHire™[8]

Designed specifically for recruiters and employers, WebHire is a multifaceted service that provides employers with *end-to-end recruiting solutions*. The service offers job-posting services as well as candidate searches. The most comprehensive of the services, *WebHire™ Enterprise*, locates and ranks candidates found through resume-scanning mechanisms. Clients will also receive a report indicating the best resources for their search. Other services available through the *WebHire™ Employment Services Network* include preemployment screening, tools for assessing employees' skill levels and information on compensation packages. An employment law advisor helps organizations design interview questions.

WebHire™ Agent is an intelligent agent that searches for qualified applicants based on job specifications. When WebHire Agent identifies a potential candidate, an e-mail is automatically sent to the candidate to generate interest. WebHire Agent then ranks applicants according to the skills information it gains from the Web search; the information is stored so that new applicants are distinguished from those who have already received an e-mail from the site.

Yahoo!® Resumes, a feature of WebHire, allows recruiters to find potential employees by typing in keywords on the Yahoo! Resumes search engine. Employers can purchase a year's membership to the recruiting solution for a flat fee; there are no per-use charges.

Job Seeker's Criteria

Position (responsibilities)
Salary
Location
Benefits (health, dental, stock options)
Advancement
Time Commitment
Training Opportunities
Tuition Reimbursement
Corporate Culture

Fig. J.3 List of a job seeker's criteria.

Boston Herald *Job Find* (**www.jobfind.com**) also charges employers to post on its site. The initial fee entitles the employer to post up to three listings. Employers have no limitations on the length of their postings.

Other Web sites providing employers with employee recruitment services include **CareerPath.com**, America's Job Bank (**www.ajb.dni.us/employer**), CareerWeb (**www.cweb.com**), **Jobs.com** and **Career.com**.

J.3.2 Problems with Recruiting on the Web

The large number of applicants presents a challenge to both job seekers and employers. On many recruitment sites, matching resumes to positions is conducted by *resume-filtering software*. The software scans a pool of resumes for keywords that match the job description. While this software increases the number of resumes that receive attention, it is not a foolproof system. For example, the resume-filtering software might overlook someone with similar skills to those listed in the job description, or someone whose abilities would enable them to learn the skills required for the position. Digital transmissions can also create problems because certain software platforms are not always acceptable by the recruiting software. This sometimes results in an unformatted transmission, or a failed transmission.

A lack of confidentiality is another disadvantage of online career services. In many cases, a job candidate will want to search for job opportunities anonymously. This reduces the possibility of offending the candidate's current employer. Posting a resume on the Web increases the likelihood that the candidate's employer might come across it when recruiting new employees. The traditional method of mailing resumes and cover letters to potential employers does not impose the same risk.

According to recent studies, the number of individuals researching employment positions through traditional means, such as referrals, newspapers and temporary agencies, far outweighs the number of job seekers researching positions through the Internet.[9] Optimists feel, however, that this disparity is largely due to the early stages of e-business development. Given time, online career services will become more refined in their posting and searching capabilities, decreasing the amount of time it takes for a job seeker to find jobs and employers to fill positions.

J.3.3 Diversity in the Workplace

Every workplace inevitably develops its own culture. Responsibilities, schedules, deadlines and projects all contribute to a working environment. Perhaps the most defining elements of a *corporate culture* are the employees. For example, if all employees were to have the same skills and the same ideas, the workplace would lack diversity. It might also lack creativity and enthusiasm. One way to increase the dynamics of an organization is to employ people of all backgrounds and cultures.

The Internet hosts demographic-specific sites for employers seeking to increase diversity in the workplace. By recruiting people from different backgrounds, new ideas and perspectives are brought forth, helping businesses meet the needs of a larger, more diverse target audience.[10]

`Blackvoices.com` and **`hirediversity.com`** are demographic-specific Web sites. BlackVoices™, which functions primarily as a portal (a site offering news, sports and weather information, as well as the ability to search the Web), features job searching capabilities and the ability for prospective employees to post resumes. HireDiversity is divided into several categories, including opportunities for African Americans, Hispanics and women. Other online recruiting services place banner advertisements on ethnic Web sites for companies seeking diverse workforces.

The Diversity Directory (**`www.mindexchange.com`**) offers international career-searching capabilities. Users selecting the **Diversity** site can find job opportunities, information and additional resources to help them in their career search. The site can be searched

according to demographics (African American, Hispanic, alternative lifestyle, etc.) or by subject (employer, position, etc.) via hundreds of links. Featured sites include **BilingualJobs.com**, *Latin World* and *American Society for Female Entrepreneurs*.

Many sites have sections dedicated to job seekers with disabilities. In addition to providing job-searching capabilities, these sites include additional resources, such as equal opportunity documents and message boards. The *National Business and Disability Council* (*NBDC*) provides employers with integration and accessibility information for employing people with disabilities, and the site also lists opportunities for job seekers.

J.4 Recruiting Services

There are many services on the Internet that help employers match individuals to positions. The time saved by conducting preliminary searches on the Internet can be dedicated to interviewing qualified candidates and making the best matches possible.

Advantage Hiring, Inc. (**www.advantagehiring.com**) provides employers with a resume-screening service. When a prospective employee submits a resume for a particular position, Advantage Hiring, Inc. presents *Net-Interview*™, a small questionnaire to supplement the information presented on the resume. The site also offers *SiteBuilder*, a service that helps employers build an employee recruitment site. An online demonstration can be found at **www.advantagehiring.com**. The demonstration walks the user through the Net-Interview software, as well as a number of other services offered by Advantage Hiring (see Fig. B.4).

Recruitsoft.com is an application service provider (ASP) that offers companies recruiting software on a *pay-per-hire* basis (Recruitsoft receives a commission on hires made via its service). *Recruiter WebTop*™ is the company's online recruiting software. It includes features such as Web-site hosting, an employee-referral program, skill-based resume screening, applicant-tracking capabilities and job-board posting capabilities. A demonstration of Recruiter WebTop's *Corporate Recruiting Solutions* can be found at **www.recruitsoft.com/process**. The demonstration shows how recruiting solutions find and rank potential candidates. More information about Recruitsoft's solution can be viewed in a *QuickTime* media player demonstration, found at **www.recruitsoft.com/corpoVideo**.

Peoplescape.com is an online service that helps employers recruit employees and maintain a positive work environment once the employee has been hired. In addition to searches for potential candidates, Peoplescape offers *PayCheck*™, *LegalCheck*™ and *PeopleCheck*™. These services help to ensure that compensation offers are adequate, legal guidelines are met and candidates have provided accurate information on their resumes and during the hiring process. For job seekers, Peoplescape offers searching capabilities, insights to career transitions, a job compensation calculator that takes benefits and bonuses into consideration when exploring a new job possibility and a series of regularly posted articles relevant to the job search.[11]

To further assist companies in their recruiting process, Web sites such as **Refer.com** reward visitors for successful job referrals. Highly sought-after positions can earn thousands of dollars. If a user refers a friend or a family member and he or she is hired, the user receives a commission.

Other online recruiting services include **SkillsVillage.com**, **Hire.com**, **MorganWorks.com** and **Futurestep.com**™.

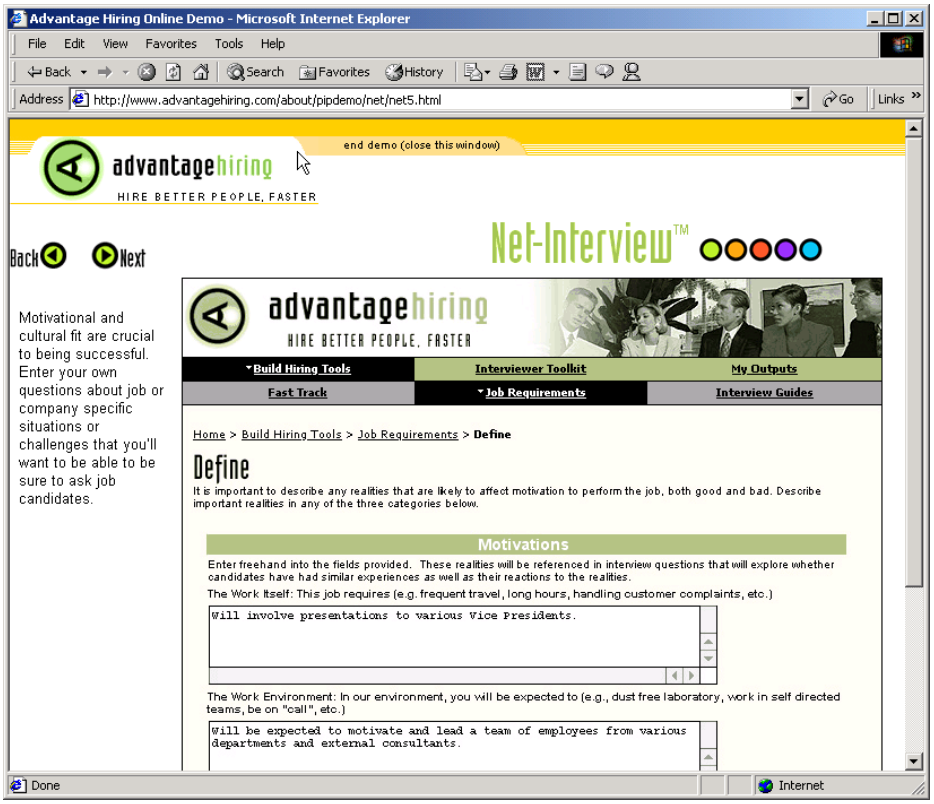


Fig. J.4 Advantage Hiring, Inc.'s Net-Interview™ service. (Courtesy of Advantage Hiring, Inc.)

J.4.1 Testing Potential Employees Online

The Internet also provides employers with a cost-effective means of testing their prospective employees in such categories as decision making, problem solving and personality. Services such *eTest* help to reduce the cost of in-house testing and to make the interview process more effective. Test results, given in paragraph form, present employers with the interested individual's strengths and weaknesses. Based on these results, the report suggests interview methods, such as asking *open-ended questions*, which are questions that require more than a "yes" or "no" response. Sample reports and a free-trial test can be found at **`www.etest.net`**.

Employers and job seekers can also find career placement exercises at **`www.advisorteam.net/AT/User/kcs.asp`**. Some of these services require a fee. The tests ask several questions regarding the individual's interests and working style. Results help candidates determine the best career for their skills and interests.

J.5 Career Sites

Online career sites can be comprehensive or industry specific. In this section, we explore a variety of sites on the Web that accommodate the needs of both the job seeker and the employer. We review sites offering technical positions, free-lancing opportunities and contracting positions.

J.5.1 Comprehensive Career Sites

As mentioned previously, there are many sites on the Web that provide job seekers with career opportunities in multiple fields. **Monster.com** is the largest of these sites, attracting the greatest number of unique visitors per month. Other popular online recruiting sites include **JobsOnline.com**, **HotJobs.com**, **www.jobtrak.com** and **Headhunter.net**.

Searching for a job online can be a conducted in a few steps. For example, during an initial visit to **JobsOnline.com**, a user is required to fill out a registration form. The form requests basic information, such as name, address and area of interest. After registering, members can search through job postings according to such criteria as job category, location and the number of days the job has been posted. Contact information is provided for additional communication. Registered members are offered access to XDrive™ (**www.xdrive.com**), which provides 25 MB of storage space for resumes, cover letters and additional communication. Stored files can be shared through any Web browser or Wireless Application Protocol (WAP)-enabled device. **Driveway.com** offers a similar service, allowing individuals to store, share and organize job search files online. An online demonstration of the service can be found at **www.driveway.com**. The animated demo walks the user through the features offered by the service. **Driveway.com** offers 100 MB of space, and the service is free.[12] Other sites, such as Cruel World (see the Cruel World feature), allow users to store and send their resumes directly to employers.

Cruel World[13]

Cruel World is a free, online career advancement service for job seekers. After becoming a registered member, your information is matched with available positions in the Cruel World database. When an available job matches your criteria, *JobCast*®, a feature of Cruel World, sends an e-mail alerting you of the available position. If you are interested, you can send your resume to the employer that posted the position, customized to the job's requirements. If you do not wish to continue your search, you can simply send a negative response via e-mail.

The client list, or the list of companies seeking new employees through Cruel World, can be viewed at **www.cruelworld.com/corporate/aboutus.asp** (Fig. B.5). Additional features on the site include hints for salary negotiation; a self-assessment link to **CareerLeader.com**, where, for a small fee, members can reassess their career goals under the advisement of career counselors and a relocation calculator for job seekers who are considering changing location.

Employers seeking to hire new talent can post opportunities through Cruel World. posting positions requires a fee. A demonstration of the service can be viewed at **www.cruelworld.com/clients/quicktour1.asp**. The demonstration is a three-step slide of JobCast.

Cruel World[13] (Cont.)

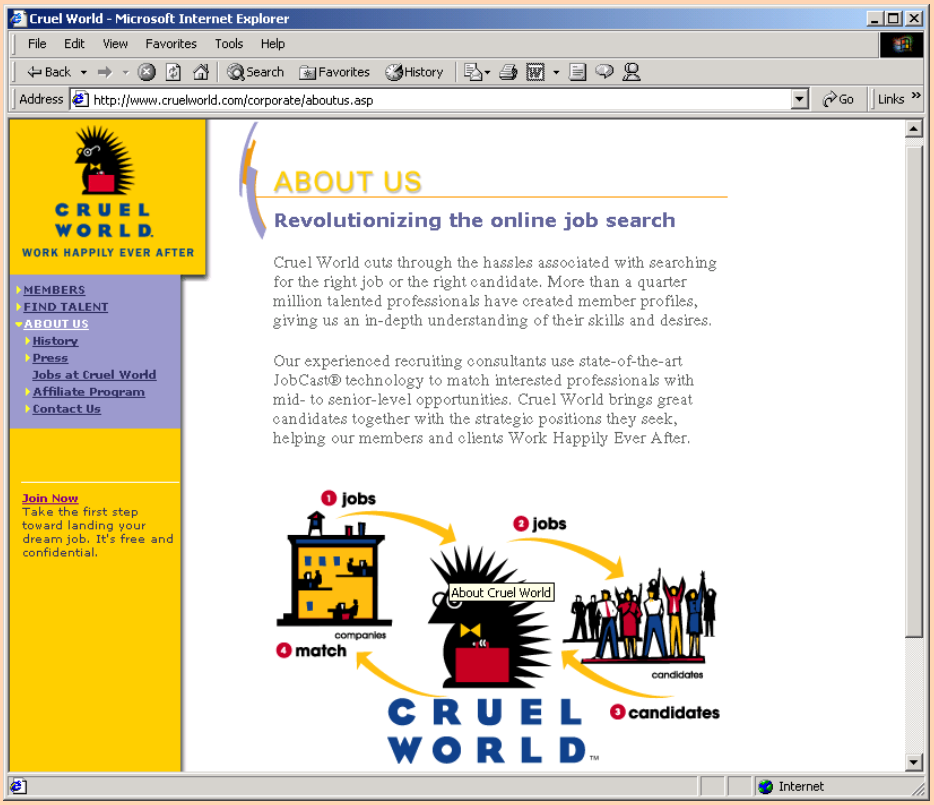


Fig. J.5 Cruel World online career services. (Courtesy of Cruel World.)

J.5.2 Technical Positions

Technical positions are becoming widely available as the Internet grows more pervasive. Limited job loyalty and high turnover rates in technical positions allow job seekers to find jobs that best suit their needs and skills. Employers are required to rehire continuously to keep positions filled and productivity levels high. The amount of time for an employer to fill a technical position can be greatly reduced by using an industry-specific site. Career sites designed for individuals seeking technical positions are among the most popular online career sites. In this section, we review several sites that offer recruiting and hiring opportunities for technical positions.

e-Fact J.3

It costs a company 25 percent more to hire a new technical employee than it does to pay an already employed individual's salary.[14]

`Dice.com` (**`www.dice.com`**) is a recruiting Web site that focuses on technical fields. Company fees are based on the number of jobs the company posts and the frequency

with which the postings are updated. Job seekers can post their resumes and search the job database for free. **JustComputerJobs.com** directs job seekers toward 39 specific computer technologies for their job search. Language-specific sites include **JustJavaJobs.com**, **JustCJobs.com** and **JustPerlJobs.com**. Hardware, software and communications technology sites are also available. Other technology recruiting sites include **HireAbility.com**, **Bid4Geeks.com**, **HotDispatch.com** and **www.cmpnet.com/careerdirect**.

J.5.3 Wireless Positions

The wireless industry is developing rapidly. According to **WirelessResumes.com**, the number of wireless professionals is 328,000. This number is expected to increase 40 percent each year for the next five years. To accommodate this growth, and the parallel demand for professionals, **WirelessResumes.com** has created an online career site specifically for the purpose of filling wireless jobs (see the **WirelessResumes.com** feature).

*The Caradyne Group (***www.pcsjobs.com)**, an executive search firm, connects job seekers to employers in the wireless technology field. Interested job seekers must first fill out a "Profile Questionnaire." This information is then entered into The Caradyne Group's database and is automatically matched to an open position in the job seeker's field of expertise. If there are no open positions, a qualified consultant from The Caradyne Group will contact the job seeker for further a interview and discussion. **Jobs4wireless.com** also provides job seekers with employment opportunities in the wireless industry.

J.5.4 Contracting Online

The Internet also serves as a forum for job seekers to find employment on a project-by-project basis. *Online contracting services* allow businesses to post positions for which they wish to hire outside resources, and individuals can identify projects that best suit their interests, schedules and skills.

e-Fact J.4

Approximately six percent of America's workforce falls into the category of independent contractor.[15]

WirelessResumes.com: *Filling Wireless Positions*

WirelessResumes.com is an online career site focused specifically on matching wireless professionals with careers in the industry. This narrow focus enables businesses to locate new employees quickly—reducing the time and expense attached to traditional recruiting methods. Similarly, candidates can limit their searches to precisely the job category of interest. Wireless carriers, device manufacturers, WAP and Bluetooth developers, e-commerce companies and application service providers (ASPs) are among those represented on the site.

In addition to searching for jobs and posting a resume, **WirelessResumes.com** provides job seekers with resume writing tips, interviewing techniques, relocation tools and assistance in obtaining a Visa or the completion of other necessary paperwork. Employers can use the site to search candidates and post job opportunities.

Guru.com (**www.guru.com**) is a recruiting site for contract employees. Independent contractors, private consultants and trainers use **guru.com** to find short-term and long-term contract assignments. Tips, articles and advice are available for contractors who wish to learn more about their industry. Other sections of the site teach users how to manage their businesses, buy the best equipment and deal with legal issues. **Guru.com** includes an online store where contractors can buy products associated with small-business management, such as printing services and office supplies. Companies wishing to hire contractors must register with **guru.com**, but individuals seeking contract assignments do not.

Monster.com's Talent Market™ offers online auction-style career services to free agents. Interested users design a profile, listing their qualifications. After establishing a profile, free agents "Go Live" to start the bidding on their services. The bidding lasts for five days during which users can view the incoming bids. At the close of five days, the user can choose the job of his or her choice. The service is free for users, and bidding employers pay a commission on completed transactions.

eLance.com is another site where individuals can find contracting work. Interested applicants can search eLance's database by category, including business, finance and marketing (see Fig. B.6). These projects, or *requests for proposals* (RFPs), are posted by companies worldwide. When users find projects for which they feel qualified, they submit bids on the projects. Bids must contain a user's required payment, a statement detailing the user's skills and a feedback rating drawn from other projects on which the user has worked. If a user's bid is accepted, the user is given the project, and the work is conducted over eLance's file-sharing system, enabling both the contractor and the employer to contact one another quickly and easily. For an online demonstration, visit **www.elance.com** and click on the **demonstration** icon.

FreeAgent (**www.freeagent.com**) is another site designed for contracting projects. Candidates create an *e.portfolio* that provides an introductory "snapshot" of their skills, a biography, a list of their experience and references. The interview section of the portfolio lists questions and the applicant's answers. Examples of e.portfolios can be found at **www.freeagent.com/splash/models.asp**. Free Agent's *e.office* offers a benefits package to outside contractors, including health insurance, a retirement plan and reimbursement for business-related expenses.

Other Web sites that provide contractors with projects and information include eWork® Exchange (**www.ework.com**), **MBAFreeAgent.com**, **Aquent.com** and **WorkingSolo.com**.

J.5.5 Executive Positions

Next, we discuss the advantages and disadvantages of finding an executive position online. Executive career advancement sites usually include many of the features found on comprehensive job-search sites. Searching for an executive position online differs from finding an entry-level position online. The Internet allows individuals to continually survey the job market. However, candidates for executive-level positions must exercise a higher level of caution when determining who is able to view their resume. Applying for an executive position online is an extensive process. As a result of the high level of scrutiny passed on a candidate during the hiring process, the initial criteria presented by an executive level candidate often are more specific than the criteria presented by the first-time job seeker. Executive positions often are difficult to fill, due to the high demands and large amount of experience required for the jobs.

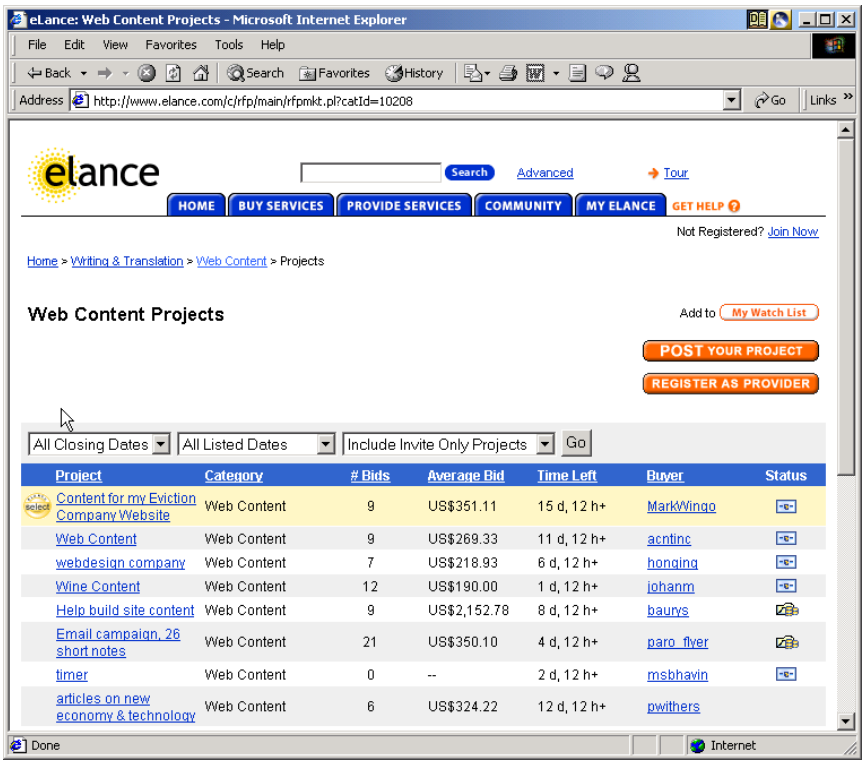


Fig. J.6 **eLance.com** request for proposal (RFP) example. (Courtesy of eLance, Inc.)

SixFigureJobs (**www.sixfigurejobs.com**) is a recruitment site designed for experienced executives. Resume posting and job searching is free to job seekers. Other sites, including **www.execunet.com**, **Monster.com**'s ChiefMonster™ (**www.chiefmonster.com**) and **www.nationjob.com** are designed for helping executives find positions.

J.5.6 Students and Young Professionals

The Internet provides students and young professionals with tools to get them started in the job market. Individuals still in school and seeking internships, individuals who are just graduating and individuals who have been in the workforce for a few years make up the target market. Additional tools specifically designed for this *demographic* (a population defined by a specific characteristic) are available. For example, journals kept by previous interns provide prospective interns with information regarding what to look for in an internship, what to expect and what to avoid. Many sites will provide information to lead young professionals in the right direction, such as matching positions to their college or university major.

Experience.com is a career services Web site geared toward the younger population. Members can search for positions according to specific criteria, such as geo-

graphic location, job category, keywords, commitment (i.e. full time, part time, internship), amount of vacation and amount of travel time. After applicants register, they can send their resumes directly to the companies posted on the site. In addition to the resume, candidates provide a personal statement, a list of applicable skills and their language proficiency. Registered members also receive access to the site's *Job Agent*. Up to three Job Agents can be used by each member. The agents search for available positions, based on the criteria posted by the member. If a match is made, the site contacts the candidate via e-mail.[16,17]

Internshipprograms.com helps students find internships. In addition to posting a resume and searching for an internship, students can use the relocation calculator to compare the cost of living in different regions. Tips on building resumes and writing essays are provided. The *City Intern* program provides travel, housing and entertainment guides to interns interviewing or accepting a position in an unfamiliar city, making them feel more at home in a new location.

In addition to its internship locators, undergraduate, graduate, law school, medical school and business school services, the Princeton Review's Web site (**www.review.com**) offers career services to graduating students. While searching for a job, students and young professionals can also read through the site's news reports or even increase their vocabulary by visiting the "word for the day." Other career sites geared toward the younger population include **campuscareercenter.com**, **brassring-campus.com** and **collegegrads.com**.

J.5.7 Other Online Career Services

In addition to Web sites that help users find and post jobs online, there are a number of Web sites that offer features that will enhance searches, prepare users to search online, help applicants design resumes or help users calculate the cost of relocating.

Salary.com helps job seekers gauge their expected income, based on position, level of responsibility and years of experience. The search requires job category, ZIP code and specific job title. Based on this information, the site will return an estimated salary for an individual living in the specified area and employed in the position described. Estimates are returned based on the average level of income for the position.

In addition to helping applicants find employment, **www.careerpower.com** provides individuals with tests that will help them realize their strengths, weaknesses, values, skills and personality traits. Based on the results, which can be up to 10–12 pages per test, users can best decide what job categories they are qualified for and what career choice will be best suited to their personal ambitions. The service is available for a fee.

InterviewSmart™ is another service offered through CareerPower that prepares job seekers of all levels for the interviewing process. The service can be downloaded for a minimal fee or can be used on the Web for free. Both versions are available at **www.career-power.com/CareerPerfect/interviewing.htm#is.start.anchor**.

Additional services will help applicants find positions that meet their unique needs, or design their resumes to attract the attention of specific employers. **Dogfriendly.com**, organized by geographic location, helps job seekers find opportunities that allow them to bring their pets to work, and **cooljobs.com** is a searchable database of unique job opportunities.

J.6 Internet and World Wide Web Resources

Information Technology (IT) Career Sites

www.dice.com
This is a recruiting Web site that focuses on the computer industry.

www.guru.com
This is a recruiting site for contract employees. Independent contractors, private consultants and trainers can use **guru.com** to find short-term and long-term work.

www.hallkinion.com
This is a Web recruiting service for individuals seeking IT positions.

www.techrepublic.com
This site provides employers and job seekers with recruiting capabilities and information regarding developing technology.

www.justcomputerjobs.com
This site serves as a portal with access to language-specific sites, including Java, Perl, C and C++.

www.bid4geeks.com
This career services site is geared toward the technical professional.

www.hotdispatch.com
This forum provides software developers with the opportunity to share projects, discuss code and ask questions.

www.techjobs.bizhosting.com/jobs.htm
This site directs job seekers to links of numerous technological careers listed by location, internet, type of field, etc.

Career Sites

www.careerbuilder.com
A network of career sites, including IT Careers, *USA Today* and MSN, CareerBuilder attracts 3 million unique job seekers per month. The site provides resume-builder and job-searching agents.

www.recruitek.com
This free site caters to jobs seekers, employers and contractors.

www.monster.com
This site, the largest of the online career sites, allows people looking for jobs to post their resumes, search job listings and read advice and information about the job-search process. It also provides a variety of recruitment services for employers.

www.jobsonline.com
Similar to **Monster.com**, this site provides opportunities for job seekers and employers.

www.hotjobs.com
This online recruiting site offers cross-listing possibilities on additional sites.

www.jobfind.com
This job site is an example of locally targeted job-search resources. **JobFind.com** targets the Boston area.

www.flipdog.com
This site allows online job candidates to search for career opportunities. It employs intelligent agents to scour the Web and return jobs matching the candidate's request.

www.cooljobs.com
This site highlights unique job opportunities.

www.careerhighway.com
This site presents an opportunity for job seekers and employers to match up and register the career-specific information for which they are searching.

www.inetsupermall.com
This site aids job searchers in creating professional resumes and connecting with employers.

www.wirelessnetworksonline.com
This site helps connect job searchers to careers for which they are qualified.

www.careerweb.com
This site highlights featured employers and jobs and allows job seekers and employers to post and view resumes, respectively.

Executive Positions

www.sixfigurejobs.com
This is a recruitment site designed for experienced executives.

www.leadersonline.com
This career services Web site offers confidential job searches for mid-level professionals. Potential job matches are e-mailed to job candidates.

www.ecruitinginc.com
This site is designed to search for employees for executive positions.

Diversity

www.latpro.com
This site is designed for Spanish-speaking and Portuguese-speaking job seekers. In addition to providing resume-posting services, the site enables job seekers to receive matching positions via e-mail. Advice and information services are available.

www.blackvoices.com
This portal site hosts a career center designed to match African American job seekers with job opportunities.

www.hirediversity.com
In addition to services for searching for and posting positions, resume-building and updating services are also available on this site. The site targets a variety of demographics including African Americans, Asian Americans, people with disabilities, women and Latin Americans.

People with Disabilities

www.halftheplanet.com
This site represents people with disabilities. The site is large and includes many different resources and information services. A special section is dedicated to job seekers and employers.

www.wemedia.com
This site is designed to meet the needs of people with disabilities. It includes a section for job seekers and employers.

www.disabilities.com
This site provides users with a host of links to information resources on career opportunities.

www.rileyguide.com
This site includes a section with opportunities for people with disabilities, which can be viewed at **www.dbm.com/jobguide/vets.html#abled**.

www.mindexchange.com
The diversity section of this site provides users with several links to additional resources regarding people with disabilities and employment.

www.usdoj.gov/crt/ada/adahom1.htm
This is the Americans with Disabilities Act home page.

www.abanet.org/disability/home.html
This is the Web site for The Commission on Mental and Physical Disability Law.

janweb.icdi.wvu.edu
The Job Accommodation Web site offers consulting services to employers regarding integration of people with disabilities into the workplace.

General Resources

www.vault.com
This site provides potential employees with "insider information" on over 3000 companies. In addition, job seekers can search through available positions and post and answer questions on the message board.

www.wetfeet.com
Similar to **vault.com**, this site allows visitors to ask questions and receive "insider information" on companies that are hiring.

Free Services

www.sleuth.com
On this site job seekers can fill out a form that indicates their desired field of employment. Job Sleuth™ searches the Internet and returns potential matches to the user's inbox. The service is free.

www.ajb.org
America's Job Bank is an online recruiting service provided through the Department of Labor and the state employment service. Searching for and posting positions on the site are free.

www.xdrive.com
This free site provides members with 25 MB of storage space for housing documents related to a user's job search. XDrive is able to communicate with all browser types and has wireless capabilities.

www.driveway.com
Similar to **XDrive.com**, this Web site provides users with 100 MB of storage space. Users can back up, share and organize information about various job searches. **Driveway.com** works on all platforms.

Special Interest

www.eharvest.com/careers/index.cfm
This Web site provides job seekers interested in agricultural positions with online career services.

www.opportunitynocs.org
This career services site is for both employers and job seekers interested in non-profit opportunities.

www.experience.com
This Web site is designed specifically for young professionals and students seeking full-time, part-time and internship positions.

www.internshipprograms.com
Students seeking internships can search job listings on this site. It also features City Intern, to help interns become acquainted with a new location.

www.brassringcampus.com
This site provides college grads and young professionals with less than five years of experience with job opportunities. Additional features help users buy cars or find apartments.

Online Contracting

www.ework.com
This online recruiting site matches outside contractors with companies needing project specialists. Other services provided through eWork include links to online training sites, benefits packages and payment services and online meeting and management resources.

www.elance.com
Similar to **eWork.com**, eLance matches outside contractors with projects.

www.freeagent.com
FreeAgent matches contractors with projects.

www.MBAFreeAgent.com
This site is designed to match MBAs with contracting opportunities.

www.aquent.com
This site provides access to technical contracting positions.

www.WorkingSolo.com
This site helps contractors begin their own projects.

Recruiting Services

www.advantagehiring.com
This site helps employers screen resumes.

www.etest.net
This site provides employers with testing services to assess the strengths and weaknesses of prospective employees. This information can be used for better hiring strategies.

www.hire.com
Hire.com's eRecruiter is an application service provider that helps organizations streamline their Web-recruiting process.

www.futurestep.com
Executives can register confidentially at **Futurestep.com** to be considered for senior executive positions. The site connects registered individuals to positions. It also offers career management services.

www.webhire.com
This site provides employers with end-to-end recruiting solutions.

Wireless Career Resources

www.wirelessresumes.com
This site connects employers and job seekers with resumes that focus on jobs revolving around wireless technology.

www.msua.org/job.htm
This site contains links to numerous wireless job-seeking Web sites.

www.jobs4wireless.com
This site searches for jobs in the wireless telecommunications field.

www.staffing.net
This site allows job seekers to discover openings in the world of wireless technology and communications.

www.wiwc.org
This site's focus is wireless communication job searching for women.

www.firstsearch.com
At this site a job seeker is able to discover part-time, full-time and salary-based opportunities in the wireless industry.

www.pcsjobs.com
This is the site for The Caradyne Group, which is an executive search firm that focuses on finding job seekers wireless job positions.

www.cnijoblink.com
CNI Career Networks offers confidential, no-charge job placement in the wireless and telecommunications industries.

SUMMARY

- The Internet can improve an employer's ability to recruit employees and help users find career opportunities worldwide.
- Job seekers can learn how to write a resume and cover letter, post them online and search through job listings to find the jobs that best suit their needs.
- Employers can post jobs that can be searched by an enormous pool of applicants.
- Job seekers can store and distribute resumes digitally, receive e-mail notification of possible positions, use salary and relocation calculators, consult job coaches and use self-assessment tools when searching for a job on the Web.
- There are approximately 40,000 career-advancement services on the Internet today.
- Finding a job online can greatly reduce the amount of time spent applying for a position. Potential candidates can also learn more about a company by visiting its Web site.
- Most sites are free to job seekers. These sites typically generate their revenues by charging employers who post their job opportunities, and by selling advertising space on their Web pages.
- Sites such as **Vault.com** and **WetFeet.com** allow job seekers to post questions about employers and positions in chat rooms and on bulletin boards.
- On many recruitment sites, the match of a resume to a position is conducted with resume-filtering software.
- A lack of confidentiality is a disadvantage of online career services.
- According to recent studies, the number of individuals researching employment positions through means other than the Internet, such as referrals, newspapers and temporary agencies, far outweighs the number of Internet job seekers.
- Career sites designed for individuals seeking technical positions are among the most popular online career sites.
- Online contracting services allow businesses to post positions for which they wish to hire outside resources, and allow individuals to identify projects that best suit their interests, schedules and skills.
- The Internet provides students and young professionals with some of the necessary tools to get them started in the job market. The target market is made up of individuals still in school and seek-

ing internships, individuals who are just graduating and individuals who have been in the workforce for a few years.

- There are a number of Web sites that offer features that enhance job searches, prepare users to search online, help design applicants' resumes or help users calculate the cost of relocating.
- Web recruiting reaches a much larger audience than posting an advertisement in the local newspaper.
- There are a variety of sites that allow employers to post jobs online. Some of these sites require a fee, which generally runs between $100–200. Postings remain on the Web site for approximately 30–60 days.
- Employers should try to post to sites that are most likely to be visited by eligible candidates.
- When designing a job posting, defining what makes a job position unique and including information such as benefits and salary might convince a qualified candidate to further investigate the position.
- The Internet hosts demographic-specific sites for employers seeking to increase diversity in the workplace.
- The Internet has provided employers with a cost-effective means of testing their prospective employees in such categories as decision making, problem solving and personality.

TERMINOLOGY

corporate culture
demographic
end-to-end recruiting solutions
entry-level position
online contracting service
open-ended question
pay-per-hire
request for proposal (RFP)
resume-filtering software

SELF-REVIEW EXERCISES

J.1 State whether each of the following is *true* or *false*. If *false*, explain why.

a) Online contracting services allow businesses to post job listings for specific projects that can be viewed by job seekers over the Web.
b) Employment networks are Web sites designed to provide information on a selected company to better inform job seekers of the corporate environment.
c) The large number of applications received over the Internet is considered an advantage by most online recruiters.
d) There is a greater number of individuals searching for work on the Web than through all other mediums combined.
e) Sixteen percent of America's workforce is categorized as independent contractors.

J.2 Fill in the blanks in each of the following statements:

a) There are approximately online career services Web sites on the Internet today.
b) The Internet hosts demographic-specific sites for employers seeking to increase in the workplace.
c) In the 24 hours following the Super Bowl, job searches occurred on **`Monster.com`**.
d) Many recruitment sites use to filter through received resumes.
e) Employers should try to post to sites that are most likely to be visited by candidates.

ANSWERS TO SELF-REVIEW EXERCISES

J.1 a) True. b) True. c) False. The large number of applicants reduces the amount of time a recruiter can spend interviewing and making decisions. Despite screening processes, many highly qualified applicants can be overlooked. d) False. The number of individuals researching employment positions through other means, such as referrals, newspapers and temporary agencies, far outweighs the number of Internet job seekers. e) False. Six percent of America's workforce is categorized as independent consultants.

J.2 a) 40,000. b) diversity. c) 5 million. d) resume-filtering software. e) eligible.

EXERCISES

J.3 State whether each of the following is *true* or *false*. If *false*, explain why.

a) RFP is the acronym for request for proposal.
b) The Internet has provided employers with a cost-effective means of testing their prospective employees in such categories as decision making, problem solving and personality.
c) Online job recruiting can completely replace other means of hiring employees.
d) Posting a job online is less expensive than placing ads in more traditional media.
e) A lack of confidentiality is a disadvantage of online career services.

J.4 Fill in the blanks in each of the following statements:

a) Finding a job online can greatly _____ the amount of time spent applying for a position.
b) _____ is an example of a Web site in which contractors can bid on projects.
c) When designing a job posting, defining what makes the position unique and including information such as _____ and _____ might convince a qualified candidate to further investigate the position.
d) The Internet hosts _____ for employers seeking to increase diversity in the workplace.
e) The Internet provides employers with a cost-effective means of testing their prospective employees in such categories as _____, _____ and _____.

J.5 Define the following

a) corporate culture
b) pay-per-hire
c) request for proposal (RFP)
d) resume-filtering software

J.6 (*Class discussion*). In this appendix, we discuss the shortcomings and advantages of recruiting on the Internet. Using the text, additional reading material and personal accounts answer the following questions. Be prepared to discuss your answers.

a) Do you think finding a job is easier on the Web? Why or why not?
b) What disadvantages can you identify?
c) What are some of the advantages?
d) Which online recruiting services do you think will be most successful? Why?

J.7 Many of the career services Web sites we have discussed in this appendix offer resume-building capabilities. Begin building your resume, choosing an objective that is of interest to you. Think of your primary concerns. Are you searching for a paid internship or a volunteer opportunity? Do you have a specific location in mind? Do you have an opportunity for future employment? Are stock options important to you? Find several entry-level jobs that meet your requirements. Write a short summary of your results. Include any obstacles and opportunities.

J.8 In this appendix, we have discussed online contracting opportunities. Visit FreeAgent (**www.freeagent.com**) and create your own e.portfolio, or visit eLance (**www.elance.com**) and search the requests for proposals for contracting opportunities that interest you.

J.9 In this appendix, we have discussed many career services Web sites. Choose three sites. Explore the opportunities and resources offered by the sites. Visit any demonstrations, conduct a job search, build your resume and calculate your salary or relocation expenses. Answer the following questions.

a) Which site provides the best service? Why?
b) What did you like? Dislike?
c) Write a brief summary of your findings, including descriptions of any features that you would add.

WORKS CITED

The notation **<www.domain-name.com>** indicates that the citation is for information found at the Web site.

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Unicode® (on CD)

Objectives

- To become familiar with Unicode.
- To discuss the mission of the Unicode Consortium.
- To discuss the design basis of Unicode.
- To understand the three Unicode encoding forms: UTF-8, UTF-16 and UTF-32.
- To introduce characters and glyphs.
- To discuss the advantages and disadvantages of using Unicode.
- To provide a brief tour of the Unicode Consortium's Web site.

Outline

K.1 Introduction
K.2 Unicode Transformation Formats
K.3 Characters and Glyphs
K.4 Advantages/Disadvantages of Unicode
K.5 Unicode Consortium's Web Site
K.6 Using Unicode
K.7 Character Ranges

Summary • Terminology • Self-Review Exercises • Answers to Self-Review Exercises • Exercises

K.1 Introduction

The use of inconsistent character *encodings* (i.e., numeric values associated with characters) when developing global software products causes serious problems because computers process information using numbers. For instance, the character "a" is converted to a numeric value so that a computer can manipulate that piece of data. Many countries and corporations have developed their own encoding systems that are incompatible with the encoding systems of other countries and corporations. For example, the Microsoft Windows operating system assigns the value 0xC0 to the character "A with a grave accent" while the Apple Macintosh operating system assigns that same value to an upside-down question mark. This results in the misrepresentation and possible corruption of data because data is not processed as intended.

In the absence of a widely-implemented universal character encoding standard, global software developers had to *localize* their products extensively before distribution. Localization includes the language translation and cultural adaptation of content. The process of localization usually includes significant modifications to the source code (such as the conversion of numeric values and the underlying assumptions made by programmers), which results in increased costs and delays releasing the software. For example, some English-speaking programmers might design global software products assuming that a single character can be represented by one byte. However, when those products are localized in Asian markets, the programmer's assumptions are no longer valid, thus the majority, if not the entirety, of the code needs to be rewritten. Localization is necessary with each release of a version. By the time a software product is localized for a particular market, a newer version, which needs to be localized as well, is ready for distribution. As a result, it is cumbersome and costly to produce and distribute global software products in a market where there is no universal character encoding standard.

In response to this situation, the *Unicode Standard*, an encoding standard that facilitates the production and distribution of software, was created. The Unicode Standard outlines a specification to produce consistent encoding of the world's characters and *symbols*. Software products which handle text encoded in the Unicode Standard need to be localized, but the localization process is simpler and more efficient because the numeric values need not be converted and the assumptions made by programmers about the character encoding are universal. The Unicode Standard is maintained by a non-profit organization called the

Unicode Consortium, whose members include Apple, IBM, Microsoft, Oracle, Sun Microsystems, Sybase and many others.

When the Consortium envisioned and developed the Unicode Standard, they wanted an encoding system that was *universal*, *efficient*, *uniform* and *unambiguous*. A universal encoding system encompasses all commonly used characters. An efficient encoding system allows text files to be parsed easily. A uniform encoding system assigns fixed values to all characters. An unambiguous encoding system represents a given character in a consistent manner. These four terms are referred to as the Unicode Standard design basis.

K.2 Unicode Transformation Formats

Although Unicode incorporates the limited ASCII *character set* (i.e., a collection of characters), it encompasses a more comprehensive character set. In ASCII each character is represented by a byte containing 0s and 1s. One byte is capable of storing the binary numbers from 0 to 255. Each character is assigned a number between 0 and 255, thus ASCII-based systems can support only 256 characters, a tiny fraction of world's characters. Unicode extends the ASCII character set by encoding the vast majority of the world's characters. The Unicode Standard encodes all of those characters in a uniform numerical space from 0 to 10FFFF hexadecimal. An implementation will express these numbers in one of several transformation formats, choosing the one that best fits the particular application at hand.

Three such formats are in use, called *UTF-8*, *UTF-16* and *UTF-32*, depending on the size of the units—in *bits*—being used. UTF-8, a variable width encoding form, requires one to four bytes to express each Unicode character. UTF-8 data consists of 8-bit bytes (sequences of one, two, three or four bytes depending on the character being encoded) and is well suited for ASCII-based systems when there is a predominance of one-byte characters (ASCII represents characters as one-byte). Currently, UTF-8 is widely implemented in UNIX systems and in databases.

The variable width UTF-16 encoding form expresses Unicode characters in units of 16-bits (i.e., as two adjacent bytes, or a short integer in many machines). Most characters of Unicode are expressed in a single 16-bit unit. However, characters with values above FFFF hexadecimal are expressed with an ordered pair of 16-bit units called *surrogates*. Surrogates are 16-bit integers in the range D800 through DFFF, which are used solely for the purpose of "escaping" into higher numbered characters. Approximately one million characters can be expressed in this manner. Although a surrogate pair requires 32-bits to represent characters, it is space-efficient to use these 16-bit units. Surrogates are rare characters in current implementations. Many string-handling implementations are written in terms of UTF-16. [*Note*: Details and sample-code for UTF-16 handling are available on the Unicode Consortium Web site at **`www.unicode.org`**.]

Implementations that require significant use of rare characters or entire scripts encoded above FFFF hexadecimal, should use UTF-32, a 32-bit fixed-width encoding form that usually requires twice as much memory as UTF-16 encoded characters. The major advantage of the fixed-width UTF-32 encoding form is that it uniformly expresses all characters, so it is easy to handle in arrays.

There are few guidelines that state when to use a particular encoding form. The best encoding form to use depends on computer systems and business protocols, not on the data itself. Typically, the UTF-8 encoding form should be used where computer systems and business protocols require data to be handled in 8-bit units, particularly in legacy systems

being upgraded because it often simplifies changes to existing programs. For this reason, UTF-8 has become the encoding form of choice on the Internet. Likewise, UTF-16 is the encoding form of choice on Microsoft Windows applications. UTF-32 is likely to become more widely used in the future as more characters are encoded with values above FFFF hexadecimal. Also, UTF-32 requires less sophisticated handling than UTF-16 in the presence of surrogate pairs.

Figure K.1 shows the different ways in which the three encoding forms handle character encoding.

K.3 Characters and Glyphs

The Unicode Standard consists of *characters*, written components (i.e., alphabets, numbers, punctuation marks, accent marks, etc.) that can be represented by numeric values. Examples of characters include: U+0041 LATIN CAPITAL LETTER A. In the first character representation, U+*yyyy* is a *code value*, in which U+ refers to Unicode code values, as opposed to other hexadecimal values. The *yyyy* represents a four-digit hexadecimal number of an encoded character. Code values are bit combinations that represent encoded characters. Characters are represented using *glyphs*, various shapes, fonts and sizes for displaying characters. There are no code values for glyphs in the Unicode Standard. Examples of glyphs are shown in Fig. K.2.

The Unicode Standard encompasses the alphabets, ideographs, syllabaries, punctuation marks, *diacritics*, mathematical operators, etc. that comprise the written languages and scripts of the world. A diacritic is a special mark added to a character to distinguish it from another letter or to indicate an accent (e.g., in Spanish, the tilde "~" above the character "n"). Currently, Unicode provides code values for 94,140 character representations, with more than 880,000 code values reserved for future expansion.

Character	UTF-8	UTF-16	UTF-32
LATIN CAPITAL LETTER A	0x41	0x0041	0x00000041
GREEK CAPITAL LETTER ALPHA	0xCD 0x91	0x0391	0x00000391
CJK UNIFIED IDEOGRAPH-4E95	0xE4 0xBA 0x95	0x4E95	0x00004E95
OLD ITALIC LETTER A	0xF0 0x80 0x83 0x80	0xDC00 0xDF00	0x00010300

Fig. K.1 Correlation between the three encoding forms.

Fig. K.2 Various glyphs of the character A.

K.4 Advantages/Disadvantages of Unicode

The Unicode Standard has several significant advantages that promote its use. One is the impact it has on the performance of the international economy. Unicode standardizes the characters for the world's writing systems to a uniform model that promotes transferring and sharing data. Programs developed using such a schema maintain their accuracy because each character has a single definition (i.e., *a* is always U+0061, *%* is always U+0025). This enables corporations to manage the high demands of international markets by processing different writing systems at the same time. Also, all characters can be managed in an identical manner, thus avoiding any confusion caused by different character code architectures. Moreover, managing data in a consistent manner eliminates data corruption, because data can be sorted, searched and manipulated using a consistent process.

Another advantage of the Unicode Standard is *portability* (i.e., software that can execute on disparate computers or with disparate operating systems). Most operating systems, databases, programming languages and Web browsers currently support, or are planning to support, Unicode.

A disadvantage of the Unicode Standard is the amount of memory required by UTF-16 and UTF-32. ASCII character sets are 8-bits in length, so they require less storage than the default 16-bit Unicode character set. However, the *double-byte character set (DBCS)* and the *multi-byte character set (MBCS)* that encode Asian characters (ideographs) require two to four bytes, respectively. In such instances, the UTF-16 or the UTF-32 encoding forms may be used with little hindrance on memory and performance.

Another disadvantage of Unicode is that although it includes more characters than any other character set in common use, it does not yet encode all of the world's written characters.

Another disadvantage of the Unicode Standard is that UTF-8 and UTF-16 are variable width encoding forms, so characters occupy different amounts of memory.

K.5 Unicode Consortium's Web Site

If you would like to learn more about the Unicode Standard, visit **`www.unicode.org`**. This site provides a wealth of information about the Unicode Standard that is insightful to those new to Unicode. Currently, the home page is organized into various sections—*New to Unicode*, *General Information*, *The Consortium*, *The Unicode Standard*, *Work in Progress* and *For Members*.

The *New to Unicode* section consists of two subsections: ***What is Unicode*** and ***How to Use this Site***. The first subsection provides a technical introduction to Unicode by describing design principles, character interpretations and assignments, text processing and Unicode conformance. This subsection is recommended reading for anyone new to Unicode. Also, this subsection provides a list of related links that provide the reader with additional information about Unicode. The **How to Use this Site** subsection contains information about using and navigating the site as well hyperlinks to additional resources.

The *General Information* section contains six subsections: ***Where is my Character***, ***Display Problems***, ***Useful Resources***, ***Enabled Products***, ***Mail Lists*** and ***Conferences***. The main areas covered in this section include a link to the Unicode code charts (a complete listing of code values) assembled by the Unicode Consortium as well as a detailed outline on how to locate an encoded character in the code chart. Also, the section contains advice on how to configure different operating systems and Web browsers so that

the Unicode characters can be viewed properly. Moreover, from this section, the user can navigate to other sites that provide information on various topics such as, fonts, linguistics and other standards such as the *Armenian Standards Page* and the *Chinese GB 18030 Encoding Standard*.

The Consortium section consists of five subsections: ***Who we are***, ***Our Members***, ***How to Join***, ***Press Info*** and ***Contact Us***. This section provides a list of the current Unicode Consortium members as well as information on how to become a member. Privileges for each member type—*full*, *associate*, *specialist* and *individual*—and the fees assessed to each member are listed here.

The Unicode Standard section consists of nine subsections: ***Start Here***, ***Latest Version***, ***Technical Reports***, ***Code Charts***, ***Unicode Data***, ***Update & Errata***, ***Unicode Policies***, ***Glossary*** and ***Technical FAQ***. This section describes the updates applied to the latest version of the Unicode Standard as well as categorizing all defined encoding. The user can learn how the latest version has been modified to encompass more features and capabilities. For instance, one enhancement of Version 3.1 is that it contains additional encoded characters. Also, if users are unfamiliar with vocabulary terms used by the Unicode Consortium, then they can navigate to the **Glossary** subsection.

The *Work in Progress* section consists of three subsections: ***Calendar of Meetings***, ***Proposed Characters*** and ***Submitting Proposals***. This section presents the user with a catalog of the recent characters included into the Unicode Standard scheme as well as those characters being considered for inclusion. If users determine that a character has been overlooked, then they can submit a written proposal for the inclusion of that character. The **Submitting Proposals** subsection contains strict guidelines that must be adhered to when submitting written proposals.

The *For Members* section consists of two subsections: ***Member Resources*** and ***Working Documents***. These subsections are password protected; only consortium members can access these links.

K.6 Using Unicode

Numerous programming languages (e.g., C, Java, JavaScript, Perl, Visual Basic, etc.) provide some level of support for the Unicode Standard. Figure K.3 shows a Java program that prints the text "Welcome to Unicode!" in eight different languages: English, Russian, French, German, Japanese, Portuguese, Spanish and Traditional Chinese. [*Note*: The Unicode Consortium's Web site contains a link to code charts that lists the 16-bit Unicode code values.]

```
1  // Fig. K.3: Unicode.java
2  // Demonstrating how to use Unicode in Java programs.
3
4  // Java core packages
5  import java.awt.*;
6
7  // Java extension packages
8  import javax.swing.*;
9
```

Fig. K.3 Java program that uses Unicode encoding (part 1 of 3).

```
10  public class Unicode extends JFrame {
11     private JLabel english, chinese, cyrillic, french, german,
12        japanese, portuguese, spanish;
13
14     // Unicode constructor
15     public Unicode()
16     {
17        super( "Demonstrating Unicode" );
18
19        // get content pane and set its layout
20        Container container = getContentPane();
21        container.setLayout( new GridLayout( 8, 1 ) );
22
23        // JLabel constructor with a string argument
24        english = new JLabel( "\u0057\u0065\u006C\u0063\u006F" +
25           "\u006D\u0065\u0020\u0074\u006F\u0020Unicode\u0021" );
26        english.setToolTipText( "This is English" );
27        container.add( english );
28
29        chinese = new JLabel( "\u6B22\u8FCE\u4F7F\u7528\u0020" +
30           "\u0020Unicode\u0021" );
31        chinese.setToolTipText( "This is Traditional Chinese" );
32        container.add( chinese );
33
34        cyrillic = new JLabel( "\u0414\u043E\u0431\u0440\u043E" +
35           "\u0020\u043F\u043E\u0436\u0430\u043B\u043E\u0432" +
36           "\u0430\u0422\u044A\u0020\u0432\u0020Unicode\u0021" );
37        cyrillic.setToolTipText( "This is Russian" );
38        container.add( cyrillic );
39
40        french = new JLabel( "\u0042\u0069\u0065\u006E\u0076" +
41           "\u0065\u006E\u0075\u0065\u0020\u0061\u0075\u0020" +
42           "Unicode\u0021" );
43        french.setToolTipText( "This is French" );
44        container.add( french );
45
46        german = new JLabel( "\u0057\u0069\u006C\u006B\u006F" +
47           "\u006D\u006D\u0065\u006E\u0020\u007A\u0075\u0020" +
48           "Unicode\u0021" );
49        german.setToolTipText( "This is German" );
50        container.add( german );
51
52        japanese = new JLabel( "Unicode\u3078\u3087\u3045\u3053" +
53           "\u305D\u0021" );
54        japanese.setToolTipText( "This is Japanese" );
55        container.add( hiragana );
56
57        portuguese = new JLabel( "\u0053\u00E9\u006A\u0061\u0020" +
58           "\u0042\u0065\u006D\u0076\u0069\u006E\u0064" +
59           "\u006F\u0020Unicode\u0021" );
60        portuguese.setToolTipText( "This is Portuguese" );
61        container.add( portuguese );
62
```

Fig. K.3 Java program that uses Unicode encoding (part 2 of 3).

```
63          spanish = new JLabel( "\u0042\u0069\u0065\u006E\u0076" +
64             "\u0065\u006E\u0069\u0064\u0061\u0020\u0061\u0020" +
65             "Unicode\u0021" );
66          spanish.setToolTipText( "This is Spanish" );
67          container.add( spanish );
68
69       } // end Unicode constructor
70
71       // execute application
72       public static void main( String args[] )
73       {
74          Unicode application = new Unicode();
75          application.setDefaultCloseOperation(
76             JFrame.EXIT_ON_CLOSE );
77          application.pack();
78          application.setVisible( true );
79
80       } // end method main
81
82    }  // end class Unicode
```

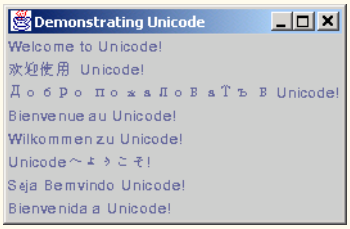

Fig. K.3 Java program that uses Unicode encoding (part 3 of 3).

The **Unicode.java** program uses *escape sequences* to represent characters. An escape sequence is in the form **\u***yyyy*, where *yyyy* represents the four-digit hexadecimal code value. Lines 24 and 25 contain the series of escape sequences necessary to print "Welcome to Unicode!" in English. The first escape sequence (**\u0057**) equates to the character "W," the second escape sequence (**\u0065**) equates to the character "e," and so on. The **\u0020** escape sequence (line 25) is the encoding for the *space* character. The **\u0074** and **\u006F** escape sequences equate to the word "to." Note that "Unicode" is not encoded because it is a registered trademark and has no equivalent translation in most languages. Line 25 also contains the **\u0021** escape sequence for the exclamation mark (**!**).

Lines 29–65 contain the escape sequences for the other seven languages. The English, French, German, Portuguese and Spanish characters are located in the **Basic Latin** block, the Japanese characters are located in the **Hiragana** block, the Russian characters are located in the **Cyrillic** block and the Traditional Chinese characters are located in the **CJK Unified Ideographs** block.

[*Note*: To display the output of **Unicode.java** properly, copy the **font.properties.zh** file to the **font.properties** files (located in the **C:\Program Files\JavaSoft\JRE\1.3.1\lib** and in the **C:\jdk1.3.1\jre\lib** directories). Save the contents of **font.properties** prior to overwriting them with the contents from **font.properties.zh**.

K.7 Character Ranges

The Unicode Standard assigns code values, which range from **0000** (**Basic Latin**) to **E007F** (***Tags***), to the written characters of the world. Currently, there are code values for 94,140 characters. To simplify the search for a character and its associated code value, the Unicode Standard generally groups code values by *script* and function (i.e., Latin characters are grouped in a block, mathematical operators are grouped in another block, etc.). As a rule, a script is a single writing system that is used for multiple languages (e.g., the Latin script is used for English, French, Spanish, etc.). The **Code Charts** page on the Unicode Consortium Web site lists all the defined blocks and their respective code values. Figure K.4 lists some blocks (scripts) from the Web site and their range of code values.

SUMMARY

- Before Unicode, software developers were plagued by the use of inconsistent character encoding (i.e., numeric values for characters). Most countries and organizations had their own encoding systems, which were incompatible. A good example is the individual encoding systems on the Windows and Macintosh platforms.

Script	Range of Code Values
Arabic	U+0600–U+06FF
Basic Latin	U+0000–U+007F
Bengali (India)	U+0980–U+09FF
Cherokee (Native America)	U+13A0–U+13FF
CJK Unified Ideographs (East Asia)	U+4E00–U+9FAF
Cyrillic (Russia and Eastern Europe)	U+0400–U+04FF
Ethiopic	U+1200–U+137F
Greek	U+0370–U+03FF
Hangul Jamo (Korea)	U+1100–U+11FF
Hebrew	U+0590–U+05FF
Hiragana (Japan)	U+3040–U+309F
Khmer (Cambodia)	U+1780–U+17FF
Lao (Laos)	U+0E80–U+0EFF
Mongolian	U+1800–U+18AF
Myanmar	U+1000–U+109F
Ogham (Ireland)	U+1680–U+169F
Runic (Germany and Scandinavia)	U+16A0–U+16FF
Sinhala (Sri Lanka)	U+0D80–U+0DFF
Telugu (India)	U+0C00–U+0C7F
Thai	U+0E00–U+0E7F

Fig. K.4 Some character ranges.

- Computers process data by converting characters to numeric values. For instance, the character "a" is converted to a numeric value so that a computer can manipulate that piece of data.
- Localization of global software requires significant modifications to the source code, which results in the increased cost and delays releasing the product.
- Localization is necessary with each release of a version. By the time a software product is localized for a particular market, a newer version, which needs to be localized as well, is ready for distribution. As a result, it is cumbersome and costly to produce and distribute global software products in a market where there is no universal character encoding standard.
- The Unicode Consortium developed the Unicode Standard in response to the serious problems created by multiple character encodings and the use of those encodings.
- The Unicode Standard facilitates the production and distribution of localized software. It outlines a specification for the consistent encoding of the world's characters and symbols.
- Software products which handle text encoded in the Unicode Standard need to be localized, but the localization process is simpler and more efficient because the numeric values need not be converted.
- The Unicode Standard is designed to be universal, efficient, uniform and unambiguous.
- A universal encoding system encompasses all commonly used characters; an efficient encoding system parses text files easily; a uniform encoding system assigns fixed values to all characters; and a unambiguous encoding system represents the same character for any given value.
- Unicode extends the limited ASCII character set to include all the major characters of the world.
- Unicode makes use of three Unicode Transformation Formats (UTF): UTF-8, UTF-16 and UTF-32, each of which may be appropriate for use in different contexts.
- UTF-8 data consists of 8-bit bytes (sequences of one, two, three or four bytes depending on the character being encoded) and is well suited for ASCII-based systems when there is a predominance of one-byte characters (ASCII represents characters as one-byte).
- UTF-8 is a variable width encoding form that is more compact for text involving mostly Latin characters and ASCII punctuation.
- UTF-16 is the default encoding form of the Unicode Standard. It is a variable width encoding form that uses 16-bit code units instead of bytes. Most characters are represented by a single 16-bit unit, but some characters require surrogate pairs.
- Without surrogate pairs, the UTF-16 encoding form can only encompass 65,000 characters, but with the surrogate pairs, this is expanded to include over a million characters.
- UTF-32 is a 32-bit encoding form. The major advantage of the fixed-width encoding form is that it uniformly expresses all characters, so that they are easy to handle in arrays and so forth.
- The Unicode Standard consists of characters. A character is any written component that can be represented by a numeric value.
- Characters are represented using glyphs, which are various shapes, fonts and sizes for displaying characters.
- Code values are bit combinations that represent encoded characters. The Unicode notation for a code value is U+*yyyy* in which U+ refers to the Unicode code values, as opposed to other hexadecimal values. The *yyyy* represents a four-digit hexadecimal number.
- Currently, the Unicode Standard provides code values for 94,140 character representations.
- An advantage of the Unicode Standard is its impact on the overall performance of the international economy. Applications that conform to an encoding standard can be processed easily by computers.
- Another advantage of the Unicode Standard is its portability. Applications written in Unicode can be easily transferred to different operating systems, databases, Web browsers, etc. Most companies currently support, or are planning to support Unicode.

- To obtain more information about the Unicode Standard and the Unicode Consortium, visit **`www.unicode.org`**. It contains a link to the code charts, which contain the 16-bit code values for the currently encoded characters.
- Numerous programming languages provide some level of support for the Unicode Standard.
- In Java programs, the **`\u`***yyyy* escape sequence represents a character, where *yyyy* is the four-digit hexadecimal code value. The **`\u0020`** escape sequence is the universal encoding for the *space* character.

TERMINOLOGY

`\u`*yyyy* escape sequence
ASCII
block
character
character set
code value
diacritic
double-byte character set (DBCS)
efficient (Unicode design basis)
encode
escape sequence
glyph
hexadecimal notation
localization
multi-byte character set (MBCS)
portability
script
surrogate
symbol
unambiguous (Unicode design basis)
Unicode Consortium
Unicode design basis
Unicode Standard
Unicode Transformation Format (UTF)
uniform (Unicode design basis)
universal (Unicode design basis)
UTF-8
UTF-16
UTF-32

SELF-REVIEW EXERCISES

K.1 Fill in the blanks in each of the following.

a) Global software developers had to _____ their products to a specific market before distribution.
b) The Unicode Standard is an _____ standard that facilitates the uniform production and distribution of software products.
c) The four design basis that constitute the Unicode Standard are: _____, _____, _____ and _____.
d) A _____ is the smallest written component the can be represented with a numeric value.
e) Software that can execute on different operating systems is said to be _____.

K.2 State whether each of the following is *true* or *false*. If *false*, explain why.

a) The Unicode Standard encompasses all the world's characters.
b) A Unicode code value is represented as U+*yyyy*, where *yyyy* represents a number in binary notation.
c) A diacritic is a character with a special mark that emphasizes an accent.
d) Unicode is portable.
e) When designing Java programs, the escape sequence is denoted by **`/u`***yyyy*.

SELF-REVIEW ANSWERS

K.1 a) localize. b) encoding. c) universal, efficient, uniform, unambiguous. d) character. e) portable.

K.2 a) False. It encompasses the majority of the world's characters. b) False. The *yyyy* represents a hexadecimal number. c) False. A diacritic is a special mark added to a character to distinguish it from another letter or to indicate an accent. d) True. e) False. The escape sequence is denoted by **\u***yyyy*.

EXERCISES

K.3 Navigate to the Unicode Consortium Web site (**www.unicode.org**) and write the hexadecimal code values for the following characters. In which block were they located?

a) Latin letter 'Z.'
b) Latin letter 'n' with the 'tilde (~).'
c) Greek letter 'delta.'
d) Mathematical operator 'less than or equal to.'
e) Punctuation symbol 'open quote (").'

K.4 Describe the Unicode Standard design basis.

K.5 Define the following terms:

a) code value.
b) surrogates.
c) Unicode Standard.

K.6 Define the following terms:

a) UTF-8.
b) UTF-16.
c) UTF-32.

K.7 Describe a scenario where it is optimal to store your data in UTF-16 format.

K.8 Using the Unicode Standard code values, write a Java program that prints your first and last name. The program should print your name in all uppercase letters and in all lowercase letters. If you know other languages, print your first and last name in those languages as well.