# A Multi-agent Based Approach to Modelling and Rendering of 3D Tree Bark Textures

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**Abstract.** Multi-Agent System (MAS) has been a wide used and effective method to solve distributed AI problems. In this paper, we simplify the biological mechanism in tree bark growth and build a MAS model to simulate the generation of tree barks. The epidermis of the bark serves as the environment of the MAS while splits and lenticels are modelled as split agents and lenticel agents. The environment records the geometrics formed by the interactions of the agents during the life cycles. Visualization of the geometrics can result in realistic 3D tree bark textures which can give much fidelity to computer graphics applications...

## 1 Introduction

The modelling of natural phenomena in computer graphics has been addressing phenomena from all kingdoms: mineral [1], animal [2], and vegetable [3]. Among these, creation and rendering of plants and ecosystems have long been a heated area of research for decades. Well developed modelling methods, such as modelling methods based on L-systems [3], have led to easy creation of artificial sceneries with high fidelity in the vegetable kingdoms. Mapping realistic tree bark texture onto the trunk surface of the generated plants can further improve their fidelity. Therefore, tree bark texture synthesis is involved.

Texture synthesis methods can be divided into 2D or 3D categories according to the representations of textures [4]. Compared with 2D textures, 3D textures contain information of height variation and can give better performance when changes of viewpoints take place. Ebert introduced some algorithms to synthesis 3D textures from the procedure approach [4]. Another way to synthesize image textures is to directly simulate their physical generation processes.

In this paper, we propose a new method based on Multi-Agent System (MAS)[5] to simulate the biological mechanism of tree bark growth and render 3D tree bark textures. Here, the dynamic features of MAS are taken advantage of to illustrate the evolution of the tree bark texture. The epidermis of a tree is modelled as the environment of the MAS where split agents and lenticel agents move and interact with each other. During this process, the environment records traces of the agents, and visualization of the geometrics of the environment at successive steps can result in 3D tree bark textures with high fidelity. Thus we

W. Banzhaf et al. (Eds.): ECAL 2003, LNAI 2801, pp. 572–579, 2003.

simulate the mechanism within the physical process of tree bark generation and produce texture sequences for computer graphical applications.

The remainder of this paper is organized as follows. Section 2 details the modelling of the system and the growth algorithms. The experiments results of texture rendering are given in section 3. Conclusion is drawn in section 4.

## 2 Multi Agent System Modelling and the Algorithms

### 2.1 Biometric Mechanism of Tree Bark Growth

As a nutrient and protection organism of a tree trunk, barks serve as a critical role in the growth of a tree, and it also serves as a criterion of identification of different trees. Cork, cork cambium, and phelloderm together make up the periderm, an impermeable outer layer that protects the inner stem tissues if the outer tissues split as the stem girth increases with age. It thus takes over the functions of the epidermis. Over time one cork cambium will be supplanted by another generated from parenchyma cells further inside. Water and nutrient of outer periderm are cut off by the newly create one and turn it into dead bark. The first formed periderm is usually replaced after one year's growth for most kinds of trees. The outer tissues split as the stem girth increases with age. [6]

According to the biometric mechanism, we build a MAS model, where surface of the tree trunk serves as the environment and the splits and lenticels are modelled as split agents and lenticel agents moving and interacting with each other in the environment. The evolvement of the system simulates the growth.

### 2.2 The Environment

Surface surrounding a segment of a tree trunk is unwrapped into a quadrate which serves as the environment. Fig. 1a and fig. 1b show a region of the environment. The environment is divided into uniform mesh grids, each of which is called a unit. A unit presents an even area where the material of the bark tissue can be deemed as identical. Each unit is associated with parameters that can affect the acts of the agents in its neighborhood. Denote a unit at the $i$th row and the $j$th column as $U(i,j), i \in (1,2,\ldots,L), j \in (1,2,\ldots,W)$, where $L$ and $W$ are the height and width of the environment. Attributes of an arbitrary unit $U(i,j)$ are defined as follows.

**Thickness.** This attribute represents the thickness of the associated area in the epidermis. It is an accumulated parameter of multiple layers and it increase as the bark grows. Environmental factors like light, water, temperature may explain the variations of this parameter. Among these factors, light is the most important one. Simplifying the variance of intensity of the light, a distribution of light is shown in fig. 1c. The thickness of unit $U(i,j)$ is calculated as

$$T_{i,j} = 1 + \alpha_{i,j} + \Gamma_{i,j}, (\alpha_{i,j} > 0, \Gamma_{i,j} \in [0.05, 0.1]) \qquad (1)$$

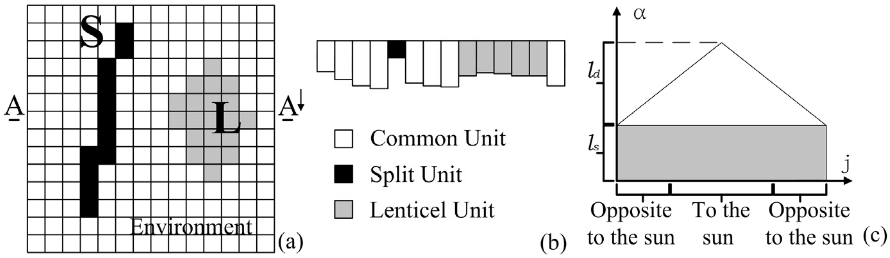


**Fig. 1.** (a) A local region of the MAS environment. **S** is a split agent and **L** is a lenticel agent. Other grids are common units. (b) A downward cross section at **(A-A)**. (c) Distribution of light $\alpha$ along a row in the environment. Light intensities in different rows may vary within a small range. Here $l_d$ stands for the proportion of direct sun rays and $l_s$ stands for the proportion made up of ambient light and diffuse light. $j$ is the index of the column in the environment.

where $\alpha_{i,j}$ describes the influence of light on the thickness and $\Gamma_{i,j}$, subjected to even distribution, is a random parameter to simulate those of other factors.
**Stress Intensity.** The stress intensity of a unit is defined as the possibility that a split will occur at the unit. With reference to maximum stress theory [7], as the stem girth increases, the outer tissues suffer a strain perpendicular to the axis of the stem, which gives rise to splits at the frailest places. Given that the tree trunk is modelled as a regular cylinder, the stress over the bark uniform, the ultimate stress is always in direct ratio to the thickness. The stress intensity of unit $U(i,j)$ is defined as

$$I_{i,j} = C_1/T_{i,j}, \tag{2}$$

where $C_1$ is a constant set to 1 in this paper for computational convenience.
**Age.** The age of a unit $U(i,j)$, noted as $A_{i,j}$, is defined as the number of growth cycles of the outmost epidermis of the region. The age of the outmost epidermis is not level for that it includes not only the regions of unstripped epidermis but also those of inner epidermises where the outer ones are stripped off.
**Categories.** Each of the units in the environment falls into one of the three categories: split unit, lenticel unit, or common unit. Units passed by split agents are labelled as split units while units in lenticel agents are labelled as lenticel units. The rest are called common units.

### 2.3 Split Agents

The splits over the tree bark are modelled as split agents. The entity $S$ in fig.1d gives an example of split agents. The upper and lower terminals of a split agent are defined as "head" and "tail" respectively. The prolongation of a split on the epidermis is abstracted as the extension of the terminals of the agent. A split agent has a limited eyesight, it is defined to be able to sense the status of the eight of its neighboring units and extend to one of them.

**Stress Template and Direction Template.** The extension of a terminal is influenced by the stress intensity in its neighborhood: the higher the stress intensity of a neighboring unit the more possible that the terminal will extend to it. Moreover, two other factors may affect their extensions: first, because of the increase in girdle, it is more possible for terminals to extend vertically than horizontally; second, a terminal tends to extend in its original direction because the tip always bears much stronger stress. We take a statistical approach to simulate the influence of the stress direction on the extension of split agents. Define a stress template as a 8-dimensional vector $P = \{p_1, p_2, ..., p_8\}^T$, where each dimension denotes the possibility that a terminal will extend to the associate direction. The subscripts here are in correspondence with the indices of the neighboring regions in fig.2a. Define a direction template to simulate the effect of the current direction of the split to its extension in the next step. The direction template is also a 8-dimensional vector noted as $Q = \{q_1, q_2, ..., q_8\}^T$, where the subscripts begin at the unit in the current direction and increase clockwise as shown in fig.2b. Denote $Q^{'} = \{q_1^{'}, q_2^{'}, ..., q_8^{'}\}^T$ as the reordered template of $Q$, where $q_i^{'}$ is associated with the same unit as $p_i^{'}$.

Stress template and reordered direction template are the main factors that define the form of the bark texture. Fig.2c and 2d give examples of the templates. For an epidermis without extraordinary distortion, the stress template and reordered direction template can be deemed as constant throughout the bark. The possibility that a terminal will extend to its $k$th neighbor is computed as

$$e_k = I_k \cdot p_k \cdot q_k^{'} \Big/ \sum_{l=1}^{8} I_l \cdot p_l \cdot q_l^{'}. \tag{3}$$

**Active-Dormant Flag.** This flag denotes the status of a terminal. “Active” means that the terminal is able to extend and “dormant” means the terminal will not prolong any more. When a split agent’s head and tail are both dormant, the agent will stop acting.

**Acting Rules for Split Agents.** A terminal is restricted to extend to one of the 5 neighbors in or at most perpendicular to its current direction. The conjunct

| | | |
|---|---|---|
| $p_2$ | $p_3$ | $p_4$ |
| $p_1$ | | $p_5$ |
| $p_8$ | $p_7$ | $p_6$ |

(a)

| | | |
|---|---|---|
| $q_8$ | $q_1$ | $q_2$ |
| $q_7$ | | $q_3$ |
| $q_6$ | $q_5$ | $q_4$ |

(b)

| | | |
|---|---|---|
| 0.1 | 0.25 | 0.1 |
| 0.05 | | 0.05 |
| 0.1 | 0.25 | 0.1 |

(c)

| | | |
|---|---|---|
| 0.1 | 0.7 | 0.1 |
| 0.05 | | 0.05 |
| 0 | 0 | 0 |

(d)

**Fig. 2.** (a) Stress template in the environment. Subscript starts from the middle left neighbor of the head and increases clockwise. (b) Direction template of a head terminal. The current extending direction of the head is upward. The index of the neighbors starts from the middle up neighbor and increase clockwise. (c) An typical instance of stress template. (d) An typical reordered direction template of a head terminal.

**Table 1.** Algorithm Of Split Growth Cycle

| | |
|---|---|
| **Step 1** | Initialization of split agents. |
| 1.1 | Evenly initialize $M$ splits each of which only has a head and a tail; |
| 1.2 | Set up the templates and attributes of their terminals; |
| **Step 2** | Traverse all the split agents and let all of their active terminals grow one step according to the acting rule. |
| **Step 3** | For a unit passed by the split, |
| 3.1 | modify the category of the unit as a split unit; set its age to zero; |
| 3.2 | change the thickness of the unit as $T_{i,j} = T'_{i,j} \cdot (1 - I_{i,j})$, where $T'_{i,j}$ is its original thickness. |
| **Step 4** | Repeat step 2 and step 3 until all the agents are dormant. |
| **Step 5** | Stop the split growth algorithm. |

**Table 2.** Algorithm Of Lenticel Growth Cycle

| | |
|---|---|
| **Step 1** | Initialize $N$ lenticel prototypes during environment initialization. |
| **Step 2** | For all the lenticels in the environment, carry the following operations: |
| 2.1 | traverse all of its neighbors and calculate their assimilation probabilities; |
| 2.2 | for a to be assimilated unit, label it as a lenticel unit and modify its thickness as $T_{i,j} = T'_{i,j} \cdot (1 - I_{i,j})$, where $T'_{i,j}$ is its original thickness. |
| **Step 3** | Stop the lenticel growth algorithm. |

trace of head and tail forms the split on the epidermis. When a terminal meets with one of the following conditions, it stops growing and be labelled as dormant.

– Reaching the upmost or the downmost bound of the environment.
– Meeting other split agents with the same age within its neighborhood.
– Meeting a lenticel agent within its neighborhood.
– All the terminals stop with a probability of $p_s$, where $p_s = 0.05$ heuristically.

**Algorithm Of Split Growth Cycle.** The extension of splits on the bark are extracted as an absolute process called split growth cycle, when only actions of the split agent are considered. The algorithm involved is listed in Table 1.

## 2.4 Lenticel Agent

The lenticels on the epidermis are modelled as lenticel agents. There are a great variety of shapes for lenticels on kinds of barks. In this paper, we try to simulate the growing mechanism of typical temperate zone broad-leaved trees that are with diamond-shaped lenticels by a method base on cellular automata [8].

**Acting Rules for Lenticel Agents.** Because of the active and rapid mitotic division of the zone below, lenticels will expand gradually during the growth. The expansion is modelled as the assimilation of directly neighboring units under the restriction of stress distribution. A lenticel agent tends to assimilate units in

**Table 3.** Algorithm Of Bark Growth Cycle

| | |
|---|---|
| **Step 1** | Environment initialization. |
| 1.1 | Determine the width and length of the environment; |
| 1.2 | Initialize the thickness and stress intensity of each unit based on the light distribution; set all the age attributes of the units as 0; |
| 1.3 | Initialize $N$ lenticel agent prototypes. |
| **Step 2** | Do split growth and lenticel growth cycles according to the acting rules. |
| **Step 3** | Evolution of the environment. |
| 3.1 | Increase the width of the environment, the incremental of columns are add to the split agents. |
| 3.2 | Increase the thickness of all the units in the environment with an incremental of the thickness of a single layer. |
| 3.3 | Modify the stress intensity in the environment with respect to the thickness. |
| 3.4 | Increase the age of all the units. |
| **Step 4** | Repeat step 2 to step 3 $A$ times and stop the growth cycle, where $A$ is the ultimate age of the tree bark. |

its 8 neighborhood. The possibility that a neighboring common unit will be assimilated is in direct ratio to its stress intensity. Note the number of all the lenticel agent's neighboring units as $n$, the stress intensity of the $k$th neighboring unit as $I_k$. The possibility that the $k$th unit will be assimilated is computed as

$$pl_k = C_2 \cdot I_k \bigg/ \frac{1}{n} \sum_{i=1}^{n} I_k, \tag{4}$$

where $C_2$ is a constant controlling the speed of the expansion.

**Algorithm Of Lenticel Growth Cycle.** The expansions of lenticels on the bark are abstracted as a step called lenticel growth cycle when only expansion of lenticel agents are considered. Algorithm in the cycle is listed in Table 2.

### 2.5 The Tree Bark Texture Generation Algorithm

The outer layers of cells of the cork are cut off from nutrients and water that feed the plant. This outer epidermis gradually dies and scales away. As the stem increases in diameter, new splits occur. These new splits often take place within the existing splits for the stress intensity are often higher than other regions. This mechanism will lead to the gullied surface of the tree bark. To simulate this process, we abstract the evolution of the environment as life cycles, which are called bark growth cycles here. The cycles are divided into the following steps.The algorithm of the bark growth cycle is detailed in Table 3.

- Environment initialization as the very phase of primary periderm growth.
- Movements of split and lenticel agents as the corresponding phase of the formation of splits and lenticels in a growth cycle.
- Evolution of the environment as the corresponding phase of tree's growth in girth and bark's growth in thickness.
- New growth cycles of agents and the environmet.


**Fig. 3.** (a) Tree bark textures at different ages. (b) Tree bark textures synthesis by different parameters. (c) Texture effects in computer synthesized sceneries.

## 3 Post-manipulation and Rendering

During the bark growth cycle, environment records the accumulated geometrics, e.g. the thickness of the units in the environment. Visualization of the geometrics can result in a vivid structure of 3D tree bark texture. The rendering and visualization of the texture involves the following computer graphic techniques.
**Visualization.** Visualization of the thickness array $A_{W*L}$ acquired from the environment, where $W$ and $L$ are the width and length of the environment. Here, each unit can be deemed as a vertex in the model, its abscissa $i$, ordinate $j$ and thickness $T_{i,j}$ provide the 3D information.
**Bump mapping.** Bump mapping [9] is a technique to add more realism to synthetic images without adding a lot of geometry. It is engaged here to add per-pixel surface relief shading and increase the apparent complexity of the surface.

**Erosion algorithm.** To implement the effect of weathering and erosive forces, erosion algorithm [10] is adopted. Random 2×2 templates are defined to erode the common units in distinct areas respectively. Thickness of an eroded unit is modified as $T_{i,j} = T^{'}_{i,j} \cdot (1 - I_{i,j})$, where $T^{'}_{i,j}$ is its original thickness.

Finally, assign colors for units with different age and thickness with colors extracted from tree bark photos and render the 3D textures. Fig. 3a and 3b give some illustrative examples of the texture synthesized by our algorithm. Ultimate effects of artificial sceneries can be achieved by mapping the 3D textures onto the tree trunk surfaces. Fig. 3c gives some examples of the artificial sceneries where tree bark textures help a lot to improve the fidelity.

## 4 Conclusion

In this paper, a model based on MAS is acquired through analysis of the mechanism in the process of tree bark growth. Evolution of the system well simulates of the tree bark growth. Sequences of 3D textures representing tree barks of different ages can be obtained by the system. Mapping these textures onto the surfaces of tree trunks can greatly enhance the fidelity of the artificial sceneries.

The proposed model has several kinds of advantages. First of all, a sequence of synthesized tree bark textures at different ages can be used to illustrate the process of tree growth. Second, simplified mechanical model and compacted number of polygons make the algorithm and rendering doable and applicable. Finally, parameters in the model have rather obvious physical meanings.

## References

[1] P. Prusinkiewicz and M. Hammel. A fractal model of mountains and rivers. In Graphics Interface 93, 174–180.
[2] Y. Chen, Y. Xu, B. Guo, and H.Y. Shum. Modeling and rendering of realistic feathers. Proc. of ACM SIGGRAPH 2002, 630–636.
[3] P. Prusinkiewicz and A. Lindenmayer. The Algorithmic Beauty of Plants. Springer-Verlag, New York, 1990.
[4] Ebert D. et al. Texturing and Modeling, A Procedural Approach, Second Edition, Cambridge 1998.
[5] G.L. Christopher. Artificial Life. The Proc. of An Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems Held September, 1987
[6] Raven, H. Peter, et al. Biology of Plants, Worth Publishers, Inc., New York, 479, 1982
[7] V.L. Kolmogorov. Stresses, strains, fracture. Moscow, Metallurgy Publ., 1970.
[8] E.F. Codd, Cellular Automata. New York: Academic Press, 1968.
[9] J.F. Blinn. Simulation of Wrinkled Surfaces. Proc. of SIGGRAPH 1978, 286–292.
[10] Donald H, M.Pauline B. Computer Graphics. Prentice Hall, 417–422, 1997.