Complementary Dual Detectors for Effective Classification

Hyi Taek Ceong[1], Young-il Kim[2], Doheon Lee[3,⋆], and Kwang-Hyung Lee[3,⋆⋆]

[1] Department of Computer Science, Yosu National University, Republic of Korea
htceong@info.yosu.ac.kr
[2] Division of Computer Science, Department of EECS, KAIST, Republic of Korea
cutty@bioif.kaist.ac.kr
[3] Department of BioSystems, KAIST, Republic of Korea
{dhlee,khlee}@bioif.kaist.ac.kr

Abstract. In this paper we introduce a method of using a pair of complementary negative detectors. When both self and non-self antigens are given, we can build a pair of complementary negative detectors using self and non-self antigens respectively and augment the results given by the detectors. When self or non-self antigens change over time, antibodies of a negative detector that gives a false positive error for the change, are used to fill the holes of the other negative detector giving a false negative error. They try to adapt to the change in complementary ways.

1 Introduction

Natural immune systems have the ability to adaptively learn, to memorize, and to recognize self and non-self to defend the body from possibly harmful foreign pathogens. An artificial immune system(AIS) is a computational system based on the metaphors of the natural immune system [1]. Recently, there has been a lot of researches on AIS and its applications [1, 5, 8, 10, 11]

Negative detectors are pattern matching systems that detect the changes of protected strings by storing strings negatively selected with respect to the strings to be protected [2]. Since the introduction of negative detectors, interest in negative detection has been growing, especially for applications in which noticing anomalous patterns is important, like computer security and computer virus detection [5].

Chao and et al. [3] outlined features of an information immune system(IIS) that could help people deal with the glut of data. As discussed in [3], negative detectors and negative selection could be used to censor unwanted information. Unlike anomaly detection or change detection, in most information systems, we can assume we have both self and non-self examples, for examples, filtering news group articles or emails.

⋆ Corresponding author

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In this paper we introduce a method of using a pair of complementary negative detectors by using both self and non-self antigens. Antibodies of a negative detector that gives a false positive error, can be used to fill the holes that the antibodies of the other negative detector do not detect, thus giving a false negative error.

2 Related Works

2.1 Immune Systems

Immunity is composed of both non-specific (innate immunity) and specific components (adaptive immunity). They work together in an interactive and cooperative way resulting in a more effective way than either could be alone. The adaptive immunity is of great interest in most AISs [10].

Adaptive immune system has four distinctive properties: specificity, diversity, memory, and self/non-self recognition. Functionally, an immune response consists of two interrelated events: recognition of antigen and response to that antigen, generation of effector cells and molecules. Antigen-presenting cells, B lymphocytes, and T lymphocytes are the primary cells of the immune response. For basic immune system information, read [10].

In the immune system, T cells go through a maturation process in the thymus. In the thymus T cells are censored against the normally occurring peptide patterns of the body(self). T cells that react with self are deleted in the thymus(negative selection). Only those T cells that survive this censoring operation are allowed to mature [4].

Clonal selection theory gives a model to explain the adaptive immunity [10]. On the surface of B cells, there are surface receptors that can bind to an antigen. When exposed to an antigen, a small group of B cells which bind to the antigen recognizes it. Coupled with a costimulatory signals from helper T cells, these B cells are stimulated. This simulation causes the B cells to proliferate and mature into effector cells(plasma cells and memory cells). The plasma cells secret antibodies specific for the antigen and often the secreted antibodies have higher affinity to the antigen(affinity maturation). The memory cells do not secret antibodies, but when they encounter the same antigen again, they proliferate more rapidly and mature into effector cells producing high affinity antibodies. During proliferation, the B cells go through the hyper somatic mutation. The hyper somatic mutation gives chances to develop B cells that can produce higher affinity antibodies to the antigen. However, the mutation may occur to develop B cells that are reactive to self antigens. These B cells go through a negative selection. They are either destroyed, inactivated or they go through receptor editing. B cells then go through a positive selection, only those B cells that have high affinity to the antigen are selected from cell death.

2.2 Negative Detectors

Antibodies that bind to antigens are called the complementary antibodies. Antigens can be represented as the complementary antibodies in a shape space [10].

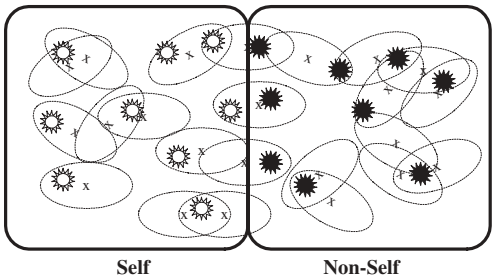

Fig. 1. Antibodies are represented as X marks and elipsoides represent the recognition region of the antibodies. White and black marks represent the complementary antibodies of self and non-self antigens.

Figure 1 shows the relation of the complementary antibodies of antigens and the recognition region of antibodies. The antigens whose complementary antibodies lie within this region are recognized by the antibody. Affinity of an antigen and an antibody can be calculated by using a similarity measure between the complementary antibody of the antigen and the antibody. Often, inverse of distance measures like hamming distance or euclidian distance are used [10].

Negative detectors are antibodies that recognize to non-self antigens and they are built with only given the self-antigens. Negative detectors are negatively selected with respect to the self-antigens. Because all negative detectors are negatively selected with respect to the self antigens, no false positive error can occur. Negative detectors are used for computer virus detection [8] and intrusion detection [5]. Forrest and et al. [2] have applied models of T cell maturation process to detect changes of computer systems. They used negative detectors to detect change of computer systems. It is difficult to build negative detectors that cover all non-self antigens [6]. There can be holes that if an antigen falls in the holes, it causes false negative errors [7].

Negative detection approach has several advantages [4]: First it has been successfully used in both engineering application and by naturally occurring biological systems. Second, if we assume a closed world, then the information can be classified in self and non-self sets. Third, it allows the detection process to be completely distributed.

3 Complementary Negative Detectors

Unlike anomaly detection or change detection, in most information systems, we can assume we have both self and non-self examples. For example, when filtering news group articles, we always have the articles that a user reads(self), and the other articles that the user does not read(non-self) and when filtering emails, we have mails that a user keep in mail boxes(self), and mails that the user classify as spam mails(non-self). After having enough such self and non-self examples, we can use them to build a pair of complementary negative detectors.

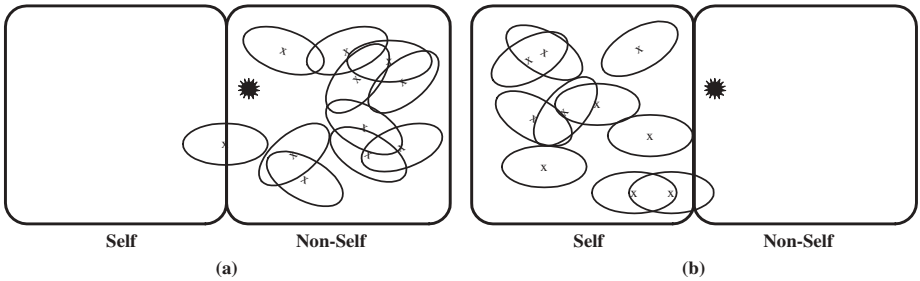

Fig. 2. The black mark shows a complementary antibody of a non-self antigen. (a) ND1 gives a false negative error.(b) ND2 gives the correct answer.

Complementary negative detectors are two detectors built by using self and non-self antigens, they detect either non-self or self antigens respectively. Negative Detector I (ND1) is a negative detector detecting non-self antigens and Negative Detector II (ND2) is a negative detector detecting self antigens. Given two sets of self and non-self antigens. Let Ab_+ be the set of the complementary antibodies of the self antigens, and Ab_- be that of the non-self antigens. We build ND1 using Ab_+ only, and ND2 with only Ab_- using negative selection [2]. Figure 2 shows a pair of complementary negative detectors, ND1 and ND2.

The final detection result can be augmented from ND1 and ND2. Since ND1 and ND2 do not give false positive errors, the final result is either that ND1 and ND2 agree with each other, or that ND1 and ND2 do not agree. If ND1 and ND2 do not agree, ND1 or ND2 is giving a false negative error.

Figure 2 gives an example of this disagreement. In this case, ND1 gives a false negative error while ND2 gives the correct answer. This is because the antibodies of ND1 do not cover the shape space correctly. This type of errors can be reduced if we can use both Ab_+ and Ab_-. In the example shown in Figure 2, we can use Ab_- to make ND1 better tuned. Ab_{ND1} and Ab_{ND2} are the set of antibodies for ND1 and ND2 respectively. For each complementary antibody(ab) in Ab_-, build a set of antibodies that recognize ab. This can be done by cloning ab with mutation, i.e., CloneMutate($\{ab\}$, Ab_-). Apply negative selection to this clones with respect to Ab_+. Update Ab_{ND1} using them. The pseudo code is given in Algorithm 1.

Algorithm 1

1. Build Ab_+ and Ab_- from self antigens and non-self antigens respectively.
2. Build ND1 using Ab_+.
   $Ab_{ND1} = \emptyset$,
   For each $ab \in Ab_-$, if ND1 do not agree with ND2,
   $Ab_{ND1} = Ab_{ND1} \cup$ NSelection(CloneMutate($\{ab\}$, Ab_-), Ab_+)
3. Build ND2 using Ab_-.
   $Ab_{ND2} = \emptyset$,
   For each $ab \in Ab_+$, if ND1 do not agree with ND2,
   $Ab_{ND2} = Ab_{ND2} \cup$ PSelection(CloneMutate($\{ab\}$, Ab_+), Ab_-)

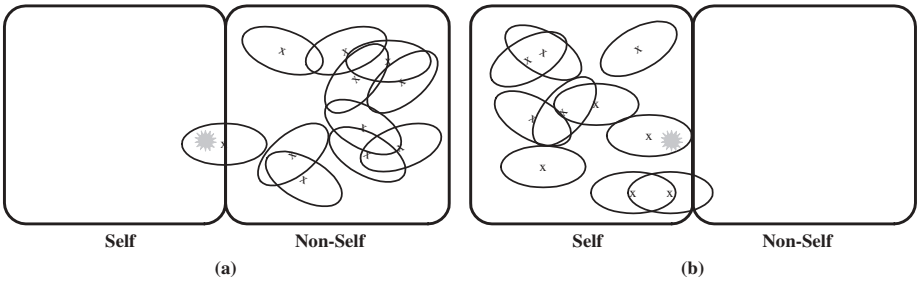

Fig. 3. Gray mark represents the complementary antibody of a new antigen. (a) ND1 gives a false positive error.(b) ND2 gives the correct answer.

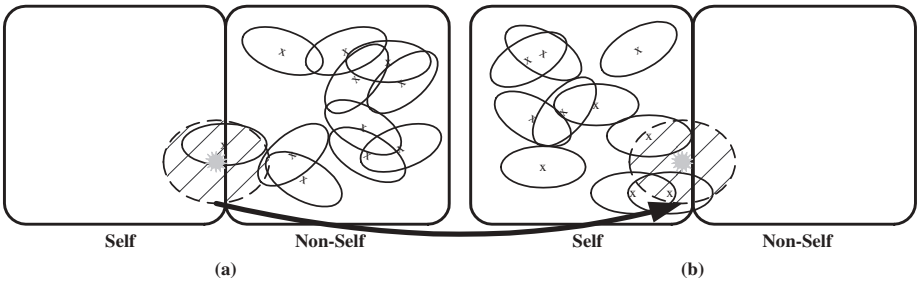

Fig. 4. Gray mark represents the complementary antibody of a new antigen. The region filled with lines shows the result of CloneMutate(PSelection(Ab_{ND1}, $\{ab\}$), $\{ab\}$). (a) ND1 gives a false positive error.(b) ND2 gives a false negative error.

PSelection() and NSelection() perform positive and negative selection on the first parameter with respect to the second parameter. CloneMutate() performs cloning with mutation elements in the first parameter are cloned according to their matching results to the second parameter, and mutation is applied to them inverse proportional to the matching result to the second parameter like CLONALG [10].

Negative detectors are built offline. They can not deal with the changes if self antigens changes over time. If a new antigen is introduced as shown in Figure 3 to ND1, it can give a false positive error. Ab_{ND1} has to be updated properly. Or if a new antigen cause an error shown in Figure 4, we can use Ab_{ND1} to fill the holes of Ab_{ND2}. As noted in [11], it is advisable in a distributed setting to choose a different rule for each machine, so each will have a different set of holes which are likely covered by some other machines. But if we can make use of non-self antigens, we can use antibodies of the pair of complementary negative detectors to cover holes. Antibodies of a negative detector that gives a false positive error, can be used to fill the holes that the antibodies of the other negative detector do not detect, thus giving a false negative error.

Suppose there is an orcle to tell if the detection results given by ND1 and ND2 are correct or not. In the case of email, for example, user's action can be

considered as the oracle. If the oracle reports an error for the detection made by complementary negative detectors, the complementary negative detectors try to adapt Ab_{ND1} and Ab_{ND2}. The pseudo code is given in Algorithm 2.

Algorithm 2

1. Build ND1 and ND2 using algorithm1
2. If the orcale signals an error for the result given by ND1 and ND2 for a new antigen, ag,
   (a) let ab be the complementary antibody of ag.
   (b) If ab is Self, $Ab'_+ = Ab_+ \cup \{ab\}$ and $Ab'_- = Ab_-$ - PSelection$(Ab_-, \{ab\})$, otherwise $Ab'_- = Ab_- \cup \{ab\}$ and $Ab'_+ = Ab_+$ - PSelection$(Ab_+, \{ab\})$.
   (c) For each cases,
      i. ND1 is false positive and ND2 is false negative
         $Ab_{\mathrm{ND1}} = Ab_{\mathrm{ND1}} \cup$ NSelection(CloneMutate($\{ab\}$, Ab_{ND1}), Ab'_+) $Ab_{\mathrm{ND2}} = Ab_{\mathrm{ND2}} \cup$ NSelection(CloneMutate(PSelection(Ab_{ND1}, $\{ab\}$), $\{ab\}$), Ab'_-)
      ii. ND1 is false negative and ND2 is false positive
         $Ab_{\mathrm{ND1}} = Ab_{\mathrm{ND1}} \cup$ NSelection(CloneMutate(PSelection(Ab_{ND2}, $\{ab\}$), $\{ab\}$), Ab'_+)
         $Ab_{\mathrm{ND2}} = Ab_{\mathrm{ND2}} \cup$ NSelection(CloneMutate($\{ab\}$, Ab_{ND2}), Ab'_-)
      iii. ND1 is false positive and ND2 is correct
         $Ab_{\mathrm{ND1}} =$ NSelection(Ab_{ND1}, Ab'_+)
      iv. ND1 is correct and ND2 is false positive
         $Ab_{\mathrm{ND2}} =$ NSelection(Ab_{ND2}, Ab'_-)
      v. ND1 is false negative and ND2 is correct
         $Ab_{\mathrm{ND1}} = Ab_{\mathrm{ND1}} \cup$ NSelection(CloneMutate($\{ab\}$, Ab_-), Ab'_+)
      vi. ND1 is correct and ND2 is false negative
         $Ab_{\mathrm{ND2}} = Ab_{\mathrm{ND2}} \cup$ NSelection(CloneMutate($\{ab\}$, Ab_+, Ab'_-)
3. $Ab_+ = Ab'_+$ and $Ab_- = Ab'_-$.

As shown in Algorithm2, when an error occurs, Ab_{ND1}, Ab_{ND2}, Ab_+ and Ab_- are updated accordingly. Then are updated according to the error types.

For example, if ND1 gives a false positive error and ND2 gives a false negative error, shown in Figure 4, then ND2 is updated using antibodies in ND1. It first searches for antibodies that recognize the ab in Ab_{ND1} and clone them with mutation. This can be written as (CloneMutate(PSelection(Ab_{ND1}, $\{ab\}$), $\{ab\}$)). Then applies negative selection to them with respect to the Ab_-. By cloning PSelection(Ab_{ND1}, $\{ab\}$), it searches for the antibodies that are near to the antibodies that recognize ab in ND1, however, it is a false positive error for ND1. On the other hand, ND2 gives a false negative error. ND2 failed to detect ab which is falsely detected by ND1. By negatively selecting PSelection(Ab_{ND1}, $\{ab\}$) with respect to Ab_-, they are used to cover the holes not deteced by ND2.

4 Discussion

In this paper, we presented a sketch of idea of using a pair of complementary negative detectors when we can use both self and non-self antigens. Negative

detectors assumed that only self antigens are known [2]. However, when we can make use of both self and non-self antigens. We can build a pair of complementary negative detectors and augment them. Also, we presented how we can use the pair of complementary negative detectors to adapt to error cases by using antibodies of complementary detectors. Antibodies of a negative detector that gives a false positive error, are used to fill the holes that the antibodies of the other negative detector do not detect, thus giving a false negative error.

There are many cases when we are not restricted to only self-antigens. Many classification applications assume they have both positive, and negative examples when they train classifiers. For examples, in spam mail filtering, they often use black list of sender information, or phrase and URL information in the body content of emails. They use rule base systems to describe spam mails. It's, in a sense, a positive detection. When building negative detectors, we should be able to incorporate existing detection schemes. For example, we can use non-self antigens to generate negative detectors more efficiently as in Algorithm 1 and Algorithm 2, this way we can ensure the generated detectors covers the non-self antigens we know.

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