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A New Artificial Immune Approach to Hardware Test Based on the Principle of Antibody Diversity

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Abstract

This paper proposes a new artificial immune approach to hardware test. A novel algorithm of generating tolerance conditions is suggested based on the principle of the antibody diversity. Tolerance conditions in artificial immune system correspond to the antibody in biological immune system. The suggested method is applied to the on-line monitoring of a typical FSM (a decade counter) and its effectiveness is demonstrated by the computer simulation.

Key words : Artificial immune system, hardware test, tolerance conditions, antibody diversity

1. Introduction

Hardware test is important in electronic systems. Specially, hardware test is indispensable to the system the hand of the person cannot be reaching such as spacecraft system. Because of this importance, many researches for hardware test have been developed. Hardware test can be implemented via n-modular redundancy (NMR) by Yinong Chen et al. [2] and S.Dutt et al. propose error-detecting and correcting codes [11] and self-checking logic circuit is proposed by [6]. In recent years, new techniques inspired by human immune systems are suggested and applied to various fields such as computer security [4][10], virus protection [4], and anomaly detection [9]. On-line testing is certainly among them. Human immune system has functions of keeping the infiltration cells (antigen) from giving damage to self cells or organ. Human immune systems generate the antibody which can detect (or match) the antigen, The artificial immune system is inspired by human immune system and mimics the principle of human immune system. The artificial immune system generates the tolerance conditions and the tolerance conditions detect (or match) the faults which are different from proper operations. Therefore, the artificial immune system provides fault-tolerant hardware architecture and suggests a new approach to reliable system.

As a pioneering work, S. Forrest et al. proposed negative selection algorithm for the detection of computer viruses and network intrusions [1]. Negative selection is used to precensor the generated antibodies against all known self pattern. D. Dasgupta brought the immune principles into multi-agent system [7] and S. Hofmeyr gave an immune system model used for distributed detection, which employs negative selection algorithm to build detector [8]. D'haeseleer proposed the greedy detector generating algorithm [9], the greedy detector algorithm has better coverage of string space and nonself detecting is more efficient than random generation of tolerance conditions.

But the previous matching algorithms imitated biological immune system in a heuristic manner. Actual biological aspect of the immunological matching was not fully exploited. That"s, these algorithms did not take into account the principle of antibody diversity which is one of the most important concepts in biological immune system.

This paper proposes a new artificial immune system for hardware test. A novel algorithm of generating tolerance conditions is suggested based on the principle of the antibody diversity. Biological immune system and the artificial immune system for fault tolerance hardware is discussed in Section II, Section III proposes new algorithm of generating tolerance conditions which is superior to the previous generation and matching algorithms, and Section IV demonstrates the new algorithm applied to decade counter which is the simple example of Finite State Machine (FSM). The paper closes with come discussion in Section V.

2 . Problem Formulation

A. Immune System

The immune system is a body-wide network of cells and organs that has evolved to defend the body against attacks by "foreign" invaders. The proper targets of the immune defenses are infectious organisms such as bacteria and virus. At the heart of the immune response is the ability to distinguish between self and nonself.

Any substance capable of triggering an immune response is known as an antigen. An antigen can be a bacterium or a virus, or even a portion or product of one of these organisms. Tissues or cells from another individual also act as antigens, that's why transplanted tissues are rejected as foreign.

Every body cell carries distinctive molecules that distinguish it as "self" and foreign molecules and it carries distinctive markers and characteristic shapes, too. One of the remarkable things about the immune system is its ability to recognize many millions of distinctive nonself molecules, and to respond by producing molecules such as these antibodies that can match and counteract each one of the non-self molecules. Antibody is a y-shaped protein on the surface of B cells that is secreted into the blood or lymph in response to an antigenic stimulus, such as a bacterium, virus, parasite, or transplanted organ, and that neutralizes the antigen by binding specifically to it.

Biological immune system consists of Lymphocytes and the two major classes of lymphocytes are B cells and T cells. B cells work chiefly by secreting soluble substances known as antibodies, and T cells contribute to the immune defenses in two major ways. Some help regulate the complex workings of the immune system, while others are cytotoxic and directly contact infected cells and destroy them. Interaction of biological immune system is shown in Fig 1.

B. Artificial immune system for hardware design

In general, normal hardware is represented as set of finite state machines (FSMs), FSMs have the states and transitions between states. When mapping artificial immune system to FSM, normal and reliable states and transitions are considered as self and the invalid states and transitions are considered as nonself. The set of tolerance conditions are considered as antibodies which detect the nonself (invalid states or transitions).

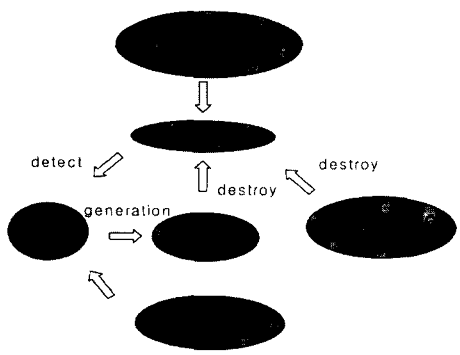

Fig.1 Interact of biological immune system

The relationship between biological immune system and hardware test system is listed in Table I.

As biological immune system creates the antibody which can detect antigen and destroy it, artificial immune system for hardware test design must generate tolerance conditions which discriminates between self and nonself. Imperfect matching is the key property of the immune system and how to generate the antibodies (the tolerance conditions) to match all the antigens is the key point in artificial immune system.

Table I. Mapping Immune system to hardware test system

Immune system	Hardware test system
Self	Valid state transition
Nonself	Invalid state transition
To create antibody	Generating of tolerance conditions
Antibody	Set of tolerance conditions (Detectors)
Antibody/antigen binding	Pattern matching

3. Tolerance conditions generation Based on Antibody diversity

Scientists long wondered how all the genetic information needed to make millions of different antibodies could fit in a limited number of genes. The answer is that antibody genes are pieced together from widely scattered bits of DNA, and the possible combinations are nearly endless. As this gene forms, it assembles segments that will determine the variable-V, diversity-D, joining-J, and constant-C segments of this antibody molecule, a typical IgM heavy chain. This is called the principle of antibody diversity.

Like biological immune system, the principle of antibody diversity should play a crucial role in the artificial immune system. To detect the more nonselfs , we need more tolerance conditions (If we have the same number of tolerance conditions as nonselfs, we can detect all nonselfs). But the memory of fault tolerance system is limited, so the smaller the number of tolerance conditions are, more effective the hardware system is. Therefore, in the case of generating tolerance conditions, antibody diversity has to be implemented.

To implement the principle of antibody diversity, the new algorithm is proposed. This algorithm mimics the human immune system more than the existing algorithms .In this algorithm, tolerance conditions are generated through genetic algorithm similar to human biological immune system. In such a way that tolerance conditions are coded as chromosomes. There are two considerable things in generating tolerance conditions. In first, tolerance conditions are as far from the self strings as possible. In second, the each tolerance conditions have to be independent of each other and this means antibody diversity. These tolerance conditions generated by considering antibody diversity have better coverage of string space, and the smaller number of tolerance conditions can discriminate the more between nonself and self.

For this algorithm, the hamming distance is used. The hamming distance counts the number of bit features that are different between two strings.

$$Hamming\ Distance = \sum_{i=1}^{N} \overline{(X i \oplus y_i)}, \quad X,\ Y \in \{0,\ 1\}$$

The hamming distance between self strings and tolerance conditions are maximized and the hamming distance between detectors (tolerance conditions) also have to be maximized each other. This algorithm is shown in Fig 2.

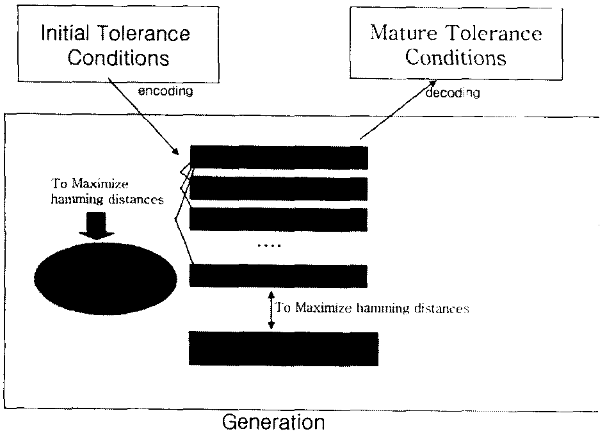

Fig. 2 Proposed algorithm of generating tolerance conditions

4. Simulation

The algorithm suggested in this paper is applies to decade counter. The effectiveness is verified through the simulation and the decade counter is the general example of FSM. Individual strings are formed from the combination of user input and previous and current states from the state machine. Fig. 3 shows one such form of the self string s. For the decade counter defined in table II, the structure of s is that given in Fig 3.

Table II Structure and function of the decade counter

Function	0 to 9 counter
States	10
Size (bits)	4
Operation	Incremental count (CEN=1,RST=0) Hold (CEN=0, RST=0) Reset (CEN=X, RST=1)

Count enable, reset /previous state/current state

10/0000/0001
10/0001/0010
....
10/1000/1001
10/1001/0000

Fig 3. Bit-string representation of the decade counter

There are 40 proper transitions in decade counter and the number of self is 40 (40x10 bits). Tolerance conditions are encoded as gene code. The size of gene code is Nr x 10 bits. (Nr is the number of tolerance conditions). To evaluate fitness of tolerance conditions, the hamming distances between self strings and tolerance conditions and the hamming distances between tolerance conditions each are maximized.

fitness
= the hamming distances (between self strings and tolerance conditions)
+ the hamming distances (between tolerance conditions)

Taking the number of tolerance condition as 25, 50, 75, and 100, nonself detection rate is showed in table III. Compared to greedy detector's efficiency, this algorithm is superior in any case seen in Fig 4.

Table III Nonself detection rate

Detector Set Size (Tolerance Conditions Size)	Nonself Strings Detectable (Proposed Algorithm)	Nonself Strings Detectable (Greedy Detector)
25	77.74 %	46.25 %
50	92.37 %	70 %
75	96.13 %	81%
100	98.17 %	88 %
125	99.22 %	91 %

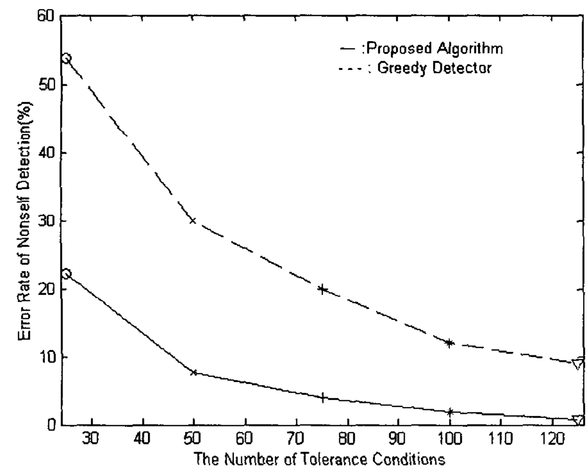

Fig. 4 Error rate of nonself detection

5. Conclusion

This paper proposed a new artificial immune approach to the on-line monitoring on the principle of antibody diversity. This algorithm is inspired by the principle of antibody diversity which is one of the most important factor in biological immune system. The suggested method resembles the generation of the antibodies in actual biological immune system. Computer simulation shows that tolerance conditions for decade counter generated by this algorithm have the better performance than greedy detector. For the future study, probabilistic approach and analysis are required in this algorithm.

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Referance

[1] S.Forrest, L.Allen, A.S. Perelson, and R.Cherukuri, "Self-Nonself Discrimination In A Computer," Proceedings of IEEE Symposium on Research in Security and Privacy, 1994, pp.202-212

[2] Y. Chen and T. Chen, "Implementing fault-tolerance via modular redundancy with comparison," IEEE Transactions on Reliability, Volume: 39 Issue: 2 , Jun 1990, pp. 217 -225[3] D.W. Bradley and A.M. Tyrrell, "Immunotronics-Novel Finite-State-Machine Architectures With Built-In Self-Test Using Self-Nonself Differentiation," IEEE Trans. On Evolutionary Computation, Vol.6, No. 3, June 2002, pp. 227-238

[4] P. K. Harmer, P. D.Williams, G. H. Grunsch, and G. B.Lamont, "An Artificial Immune System Architecture For Computer Security Applications," IEEE Transactions on Evolutionary Computation, Vol.6, No.3, June 2002, pp. 252-280

[5] D.Dagupta, Ed., Artificial Imune Systems and Their Applications, Heidelberg, Germany:Springer-Verlag, 1999

[6] P.K. Lala, Digital Circuit Testing and Testablilty, New York: Academic, 1997

[7] D.Dasgupta, "An artificial immune system as a multi-agent decision support system," Proc. IEEE Int. Conf. Systems, Man and Cybernetics, Oct. 1998,pp.3816-3820

[8] S.A Hofmeyr and S. Forest, "Architecture for an artificial immune system," Evol.Comput.,vol.8 no.4, pp.443-473

[9] P.D"haeseller, S. Forrest, P. Helman, "An Immunological Approach to Change Detection : Alogorithms, Analysis and Implications," Proc. Of IEEE Symp. On Security and Privacy, 1996

[10] S. Forrest, S.A. Hofmeyr, A. Somayaji, and T.A. Longstaff, "A Sense of Self for Unix Processing," Proc.IEEE Symp. Computer Security and Privacy, May, 1996, pp.120-128

[11] S.Dutt and N.R Mahapatra, "Node-covering, error-correcting codes and multiprocessors with very high average fault tolerance," IEEE Trans. Comput., Vol. 46, Sep.1997, pp.997-1914

[12] R.A. Goldsby, T.J. Kindt, and B.A Osborne, Kuby Immunology, 4th ed. W.H Freeman and Company: New York, 2000

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