An Immunotronic Approach for Hardware Fault Detection and its Application to the Design of Stigmergy Engine

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Abstract: A novel immunotronic (immunological electronic) approach for fault detection in hardware based on the symbiotic evolution is proposed in this paper. And the suggested method is applied for real-time fault detection of stigmergy engine inside a bionetwork processor

1. Introduction

In the twentieth century, various problems in theoretical immunology were solved and the mathematical models and the analysis methods of immune phenomena were developed. Especially, the development of the immune-inspired hardware fault detection technique or immunotronics (immunological electronics) has been suggested in [1]. Recently, Lee *et al.* suggested the GA-based design method of the immunotronic system to improve the fault detection rates [2]. In the immune-inspired fault detection technique, imperfect matching enables the system to detect *faults (nonselfs)* though they are not known to the system and faults can be detected by tolerance conditions which are generated from the information of *proper states (selfs)* by negative selection algorithm. Tolerance conditions in the immunotronic system correspond to antibodies in the biological immune system and the most important problem in designing the immunotronic system is how to generate tolerance conditions effectively and how to distinguish faults (nonselfs) from proper states (selfs). In this paper, tolerance conditions are generated conditions through symbiotic evolution algorithm from the perspective of the antibody diversity. This principle enables B cells to generate the diverse antibodies with limited number of DNA and to detect more nonselfs with lesser antibodies [3].

The rest of the paper is organized as follows: In Section 2, the symbiotic evolutionary algorithm of generating tolerance conditions are proposed. In Section 3, the algorithm is applied to stigmergy engine inside a bionetwork processor and its performance is demonstrated by the experiment. Section 4 concludes the paper with some discussions.

2. Design of Fault Detection System Through Symbiotic Evolution

In this paper, symbiotic evolutionary algorithm is employed to generate the tolerance conditions. In the SGA, an individual (or a chromosome) is composed of a series of unknown parameters and represents the full solution. The fitness value is assigned to each individual according to the cooperative performance of the constituent unknown parameters. In the symbiotic evolution, however, an individual does not represent the full solution but represents only an unknown parameter, which is only a part of the full solution. A collection of the unknown parameters (or individuals) represents a full solution. Usually, the performance of the collection of the individuals is better than the sum of the performances of the constituent individuals and that is the reason why we call the algorithm as *symbiotic evolution*.

In this paper, tolerance conditions are generated from the perspective of the negative selection and the principle of the antibody diversity. That is, the tolerance conditions are generated in such a way that they are as far away as possible from the selfs in term of Hamming distance (*negative selection*) and are as different as possible from other tolerance conditions to accomplish the diversity of the antibodies (*antibody diversity*). In the symbiotic evolution, a collection of individuals represents a full solution and a fitness value is assigned to the collection of individuals. So, we have to break up the single fitness value and assign the divided values to the constituent individuals. In this paper, we employ the following fitness sharing strategy. The strategy is a bit motivated by Lin's work [4] but it is tailored to this problem. The main scheme of algorithm is shown in Fig.1.

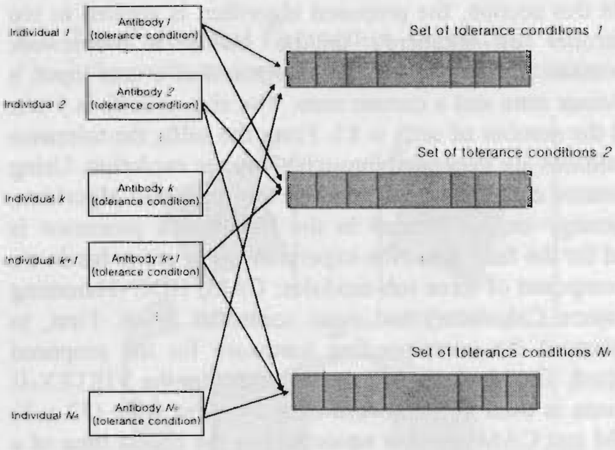

Fig.1. The basic scheme of symbiotic evolution

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Here, it is assumed that a population is composed of N_A individuals.

Step 1) Select N_T tolerance conditions from a population of N_A individuals in a random manner, where N_T is the size of the set of the tolerance conditions and $N_T << N_A$.

Step 2) Compute the fitness value for the set of the selected N_T tolerance conditions, break up the value and distribute each divided value to the corresponding constituent N_T tolerance condition. The fitness value for the set of the selected N_T tolerance conditions is defined as

$$Fitness = \sum_{k=1}^{N_T} \left\{ \min_{j=1}^{|S|} \left(H\left(\sigma_j, \tau_k\right) \right) \right\} + \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} H\left(\tau_i, \tau_j\right)$$

and the fitness value for each constituent tolerance condition is computed by

$$f_k = \min_{j=1}^{|S|} \left(H\left(\sigma_j, \tau_k\right) \right) + \frac{1}{N_T} \sum_{i=1}^{N_T} \sum_{j=1}^{N_T} H\left(\tau_i, \tau_j\right)$$

N_T : the size of the set of the tolerance conditions

σ_j : jth self string $\left(1 \le j \le |S|\right)$

τ_k : kth tolerance condition $\left(1 \le k \le N_T\right)$

where

$$\mathrm{H}(\mathrm{X}, \mathrm{Y}) = \sum_{i=1}^{N} \left(x_i \oplus y_i\right),\ X, Y \in \{0, 1\} : \text{Hamming Distance}\ .$$

Step 3) Repeat the above steps 1 and 2 N_R times until every tolerance condition is selected a sufficient number of times. In each trial, we accumulate the fitness value f_k for each constituent tolerance condition and count the times when each individual is selected.

Step 4) Divide the accumulated fitness value of each individual by the number of times it was selected

3. Experiment and Results

In this section, the proposed algorithm is applied to top controller of stigmergy engine inside a bionetwork processor. The self strings are composed of a user input, a previous state and a current state. The size of selfs is 9 bits and the number of selfs is 85. From the selfs, the tolerance conditions are generated through symbiotc evolution. Using tolerance conditions generated by the suggested algorithm, stigmergy engine located in the bionetwork processor is used for the fault detection experiment. The entire hardware is composed of three sub-modules; CAM, HDC (Hamming Distance Calculator) and main controller block. First, to implement the corresponding hardware for the proposed method, The block RAM memory built into the VIRTEX-II devices is used as a 32-word deep by 9-bit wide (32 x 9) CAM and CAM speed is equivalent to the access time of a VIRTEX block RAM for a single clock cycle match (read), and a one or two clock cycles write. To calculate the distance between present and next state, hamming distance calculator is designed and implemented as fully combinational one. To give the control signal for CAM and generate the detached data from CAM contents, dedicated main controller block is also designed. The implementation results are summarized in table 1.

Table 1 . Implementation results

	Gate count	Memory element	Features description
CAM	49	1185	Single clock operation
HDC	41	0	Combinational logic
Main controller	79	30	Data detachment and control signal generation
Total	169	1215	

Using experimental results, we compute the nonself detection rates shown in Table. 2. From the table, it should be noted that the suggested method demonstrates good performance for fault detection.

Table 2.Nonself detection rates

The number of tolerance coditions	40	60	80	100
Nonself detection rates	68.21 %	76.10 %	83.07 %	90.25 %

4. Conclusion

In this paper, a novel immunotronic approach to hardware fault detection has been proposed. In the implementation of the tolerance condition generation, symbiotic evolution is employed. The suggested method is applied for real-time fault detection of stigmergy engine inside a bionetwork processor and the suggested method demonstrates good performance for fault detection.

References

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