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Jordi Madrenas
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Evolvable Systems: From Biology to Hardware

6th International Conference, ICES 2005
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Preface

The flying machines proposed by Leonardo da Vinci in the fifteenth century, the self-reproducing automata theory proposed by John von Neumann in the middle of the twentieth century and the current possibility of designing electronic and mechanical systems using evolutionary principles are all examples of the efforts made by humans to explore the mechanisms present in biological systems that permit them to tackle complex tasks. These initiatives have recently given rise to the emergent field of bio-inspired systems and evolvable hardware. The inaugural workshop, Towards Evolvable Hardware, took place in Lausanne in October 1995, followed by the successive events of the International Conference on Evolvable Systems: From Biology to Hardware, held in Tsukuba (Japan) in October 1996, in Lausanne (Switzerland) in September 1998, in Edinburgh (UK) in April 2000, in Tokyo (Japan) in October 2001, and in Trondheim (Norway) in March 2003.

Following the success of these past events the sixth international conference was aimed at presenting the latest developments in the field, bringing together researchers who use biologically inspired concepts to implement real systems in artificial intelligence, artificial life, robotics, VLSI design, and related domains. The sixth conference consolidated this biennial event as a reference meeting for the community involved in bio-inspired systems research.

All the papers received were reviewed by at least three independent reviewers, thus guaranteeing a high-quality bundle for ICES 2005. The conference included three keynote talks entitled: "Perspectives in Complex Systems Research", "Neural Coding of Auditory Information" and "Evolutionary Approaches to Articulated Robot Locomotion". The conference program consisted of 21 technical presentations and a panel debate. Additionally, a varied social program was set up to foster the exchange of ideas in an enjoyable environment.

We would like to thank the reviewers for their time and effort in reviewing all of the submitted papers. We would also like to thank the other members of the Organizing Committee. We wish to thank the following for their direct support of this conference: the Technical University of Catalunya (UPC), the Department of Electronics of the Technical University of Catalunya, the Spanish Ministry of Education, Culture and Sports, the Funding Agency for Universities and Research of the Generalitat de Catalunya (AGAUR), and Xilinx, Inc. Last, but not least, we would like to thank all the authors who invested so much time and effort in their research work and decided to join us in making ICES 2005 a successful event.

And what is to come next? It is not so easy to make forecasts in a research field that is moving as fast as ours about findings and understanding relating to the basic mechanisms that underlie the living forms we can observe. Of course, technology will play a major role in allowing for an actual realization of these principles, and this is where nanotechnology and new FPGA architectures will provide the necessary substrate. However, in our opinion it will be the close cooperation between bioscientists, mathematicians and engineers that will result in a framework able to permit the construction of artifacts with emergent properties similar to those we can see even in the simplest living being. For sure in the next ICES conference we will see most of the topics that we have covered in the past, including evolving hardware design (both digital and analogue); evolutionary hardware design methodologies; self-repairing hardware; self-replicating hardware; embryonic hardware and self-developing systems; morphogenesis; neural hardware and adaptive hardware platforms; autonomous robots; evolutionary robotics; and molecular computation. As for the new topics that will emerge in this research field, it is our feeling that the breakthroughs coming in the life sciences in the coming years will provide avenues for facing challenges that, like consciousness, still constitute what Schopenhauer termed the world's knot.

We hope you enjoy reading these proceedings as much as we enjoyed putting them together.

September 2005

J. Manuel Moreno
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An Adaptive Self-tolerant Algorithm for Hardware Immune System

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Abstract. Hardware immune systems have been studied with some initial achievements in recent years. Hardware immune systems are inspired by biological immune systems and they are expected to have many interesting characteristics, such as self-adaptive, self-learning and fault tolerant abilities. However, as novel intelligent systems, hardware immune systems are faced with many problems. This paper focuses on autoimmunization that is an inevitable problem when designing a complex hardware immune system. After the co-stimulation mechanism of biological immune system is simply introduced as a metaphor, a novel self-adaptive and self-tolerant algorithm for hardware immune systems is proposed in this paper. Inspired by the co-stimulation mechanism, the algorithm endows hardware immune systems with the capability of self-tolerance by automatically updating detector set and making the self set more complete. It can increase the accuracy of detection and decrease the rate of false positive effectively. Results of simulation experiments demonstrate the validity of this algorithm.

1 Introduction

Many works have been devoted to computational methods that are inspired by biological immune system in recent years [1-2]. As novel computational methods of Computational Intelligence (CI), this kind of research is called as Artificial Immune Systems (AISs) or methods. Among the many works about AIS, the concept of hardware immune systems is a younger one, which is proposed as a novel approach to designing a kind of hardware system with the fault tolerant ability [3-4].

So far, some works about hardware immune system have already been done. The architecture of a hardware immune system is firstly discussed and studied by D. W. Bradley and A. M. Tyrrell [3]. Also, A. M. Tyrrell and his colleagues proposed the concept of Immunotronics, and tried to construct a new theory about the design of fault tolerant hardware [5-6]. Based on Embryonic Array, R. Canham and A. M. Tyrrell proposed a multi-layered hardware artificial immune system with learning ability, which used the fact that the immune system consists of acquired immune subsystem and innate immune subsystem for reference. The acquired layer of the immune system monitors the behaviors of system for unusual activities, and the non-learning innate layer is then employed to localize the fault if possible [7]. R. Canham and A. M. Tyrrell also developed a novel

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artificial immune system, in which a detector of an immune system can be defined as a column in a 2-D feature space, and the generation and learning of detectors are fully automatic. It has been applied to robotics as an error detection system [8]. A. Tarakanov and D. Dasgupta proposed a novel architecture for building immunochips. The immunochip, by which information can be processed in a parallel and distributed manner, was evaluated with the problem of detecting dangerous ballistic situations in near-Earth space [9].

Generally, when the negative selection algorithm [10] is used to perform error detection in a complex fault tolerant hardware system, a complete set of self strings can not be obtained. Therefore, a part of matured detectors could become a threat to the system under monitoring because these detectors may match some unknown self strings. This problem is similar to the autoimmunization in biological immune system. For complex hardware systems, this problem seems inevitable, but there is no effective solution up to now.

Inspired by the co-stimulation mechanism which is used to maintain self-tolerance in biological immune systems, an adaptive self-tolerant algorithm for hardware immune system is proposed in this paper, it adopts Concurrent Error Detection (CED) technology [11] to provide the co-stimulation signal for the error detection system. It is named as ASTA-CED (the Adaptive Self-tolerant Algorithm with Concurrent Error Detection). The co-stimulation signal drives the error detection system to update the detector set automatically, delete detectors which bring autoimmune behaviors and generate new valid detectors. Therefore, ASTA-CED can avoid the occurrences of autoimmunization. Simulation experiments are carried out to show that this proposed algorithm can increase the accuracy of detection and decrease the ratio of false positives effectively.

The co-stimulation mechanism of biological immune system is simply discussed in section 2. Section 3 gives an introduction of the ASTA-CED in detail. Section 4 demonstrates the design of simulation experiments and the experimental results. And discussions are also given in section 4. Finally, section 5 is devoted to conclusions and future studies.

2 Immune Metaphor

In the natural immune system, an inactive T-cell's activation needs not only the antigen recognition signal (the first signal), but also co-stimulation (the second signal) [12]. The source of the second signal can be various, mainly coming from the combination of B7 molecules on the surface of antigen presentation cells (APC) and CD28 molecules on the surface of T-cells. Although the second signal does not have specificity, without the second signal, a T-cell that has already obtained the first signal will become an anergy cell (which can not take its own responsibility), and even die. The activation process of a T-cell is presented in Fig. 1 [12].

Among many kinds of cells interacting with T-cells, only the professional APCs (playing a professional role of presenting a peptide of an antigen to T-cells and providing other corresponding signals) can provide the first and second signals to activate T-cells at the same time [12]. If a T-cell recognizes an antigen's peptide from

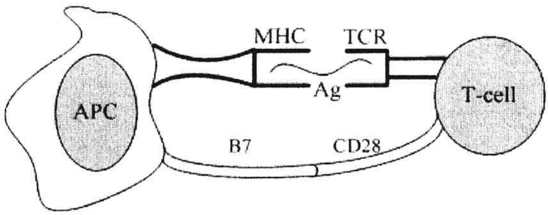

Fig. 1. This briefly shows that the activation of a T-cell should get the first and second signals. Here both first and second signals come from APC. However, the second signal, as a signal of co-stimulation, can come from various immune cells or molecules.

cells other than professional APCs, generally it will become an anergy cell because of the lack of the second signal. In fact, this is not likely to be a bad thing, because the antigen recognized is generally a self antigen at this time. In the biological immune system, new birth lymphocytes will undergo a maturation process, in which lymphocytes that bind with self proteins are destroyed. Hence, when released within the body, binding to a protein indicates it is non-self and may be a harmful pathogen. But the fact indicates that not all self proteins are presented to the maturing lymphocytes. This means some of the matured lymphocytes are still dangerous to the body. Thus, making the lymphocytes threatening the body become anergy cells or dies. This process is very helpful for the maintaining of self-tolerance [12].

Artificial hardware immune systems are presented with a similar problem, the current learning requires a period of fault free operation during which all the self states are presented. Although there are applications where this is possible, this can become a non-trivial task in some complex systems [7]. So, a mechanism to provide the second signals for artificial hardware immune systems is required.

3 ASTA-CED Algorithm

The negative selection algorithm is used for performing the detection of invalid state transitions. The negative selection algorithm, developed by Forrest and her colleagues [10, 13], is based on the generation process of T-Cells within the immune system. Forrest and her colleagues use a string to represent the self and non-self individuals. Partial matching between these self strings and non-self strings is used as a matching rule to distinguish between self and non-self. A set of detector strings are generated such that they do not match with all self strings, and they only match with non-self strings. Hence, the matching between a detector and the strings being protected gives an indication that some abnormal behaviors have occurred, and this indication is used as the first signal to the error detection system. In ASTA-CED algorithm, strings are used for representing the system's state transition but not just states because invalid state transitions can occur between valid states.

Concurrent Error Detection (CED) is widely used in highly dependable computing systems. It is a kind of on-line parity checking technology [11]. In the ASTA-CED algorithm, CED is used for performing parity checking on system's outputs and gen-

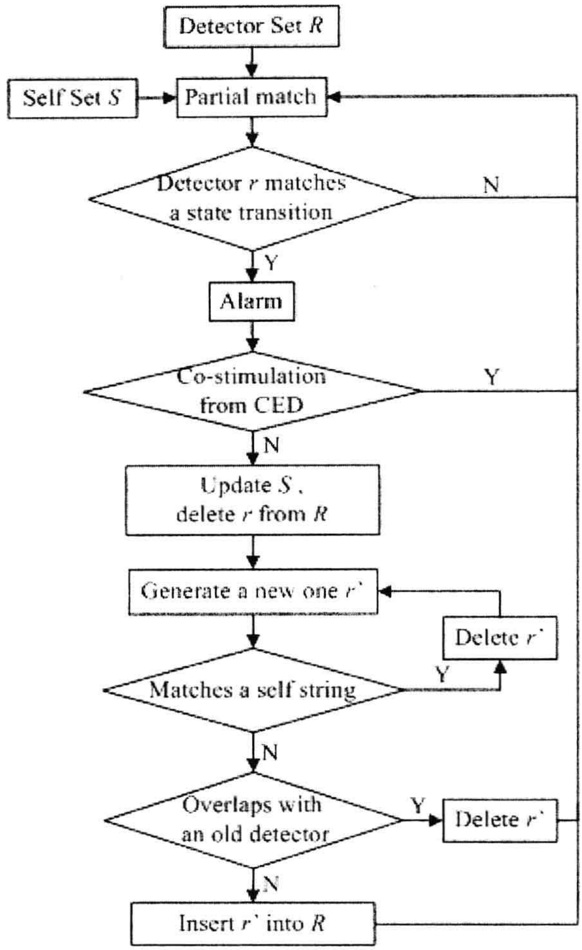

Fig. 2. This is the flow chart of ASTA-CED algorithm. The CED is used as a co-stimulation signal in ASTA-CED. Driven by this co-stimulation signal, the self set becomes more and more complete and the detector set evolves to be more and more efficient.

erating co-stimulation signals, because it is a simple and comparatively inexpensive technology to implement.

The ASTA-CED algorithm can be specified as shown in Fig. 2, in which S is the set of self (valid state transition) strings, and R is the set of detectors. The following is the description of the algorithm shown in Fig. 2. Here, it assumes that the initial set S is incomplete because a complete self set can not be obtained in general.

(1) Perform partial matching between state transitions and detectors in R one by one;
(2) If a detector r matches a state transition string, go to (3), or else back to (1);
(3) Report the error, if there is no co-stimulation from CED, go to (4), or else back to (1);