ARTIFICIAL IMMUNE SYSTEM: A REVIEW

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ABSTRACT

Artificial immune systems can be defined as abstract or metaphorical computational systems developed using ideas, theories, and components, extracted from the immune system. Most AIS aim at solving complex computational or engineering problems, such as pattern recognition, elimination, and optimisation. This is a crucial distinction between AIS and theoretical immune system models. While the former is devoted primarily to computing, the latter is focused on the modelling of the IS in order to understand its behaviour, so that contributions can be made to the biological sciences. It is not exclusive, however, the use of one approach into the other and, indeed, theoretical models of the IS have contributed to the development of AIS. This paper discusses the concept of artificial immune system. AIS has various algorithms such as: Immune Theory, Clonal Selection, negative selection. All these are explained in this paper.

Keywords: AIS, Immune, Theory, Clonal Selection.

I. INTRODUCTION

The vertebrate immune system (IS) is one of the most intricate bodily systems and its complexity is sometimes compared to that of the brain. With the advances in the biology and molecular genetics, the comprehension of how the immune system behaves is increasing very rapidly. The knowledge about the IS functioning has unraveled several of its main operative mechanisms. These mechanisms have demonstrated to be very interesting not only from a biological standpoint, but also under a computational perspective. Similarly to the way the nervous system inspired the development of artificial neural networks (ANN), the immune system has now led to the emergence of artificial immune systems (AIS) as a novel computational intelligence paradigm [1].

The field of Artificial Immune Systems (AIS) is one of the recent biologically inspired approaches to emerge from computer science. The natural immune system is an adaptive learning
system that employs many parallel and complementary mechanisms for defense against foreign pathogens. It is a distributed system, capable of learning to identify previously unseen invaders and remembering what it has learnt. Numerous immune algorithms now exist, based on processes identified within human immune systems. AIS computational technique has led to the development of useful computational tools for the solution of complex problems such as in pattern recognition, fault detection, classifications, computer security, and optimization [2].

**Basic Immune System Recognition**

Biological immune system has intelligent capabilities of detecting or recognizing self / non self antigen in the body [2]. The primary immune defense, also referred to as innate immunity is the immune mechanism our bodies are born with. If the innate immune system cannot remove the pathogen, then the adaptive (secondary immune response) immune system will take over. This vertebrate immune system exhibits some remarkable properties that mentioned in [3], [4], including:

- Feature extraction to determine unique signature of the antigen.
- Learn to recognize new patterns / antigens.
- Work as distributed patter recognizers.
- Use content-addressable memory to retrieve known pattern / antigens.
- Use of selective proliferation and self replication for quick recognition and response.
- Eliminate / neutralize the effect of antigens in a systematic fashion.

Figure 1 adopted from [7], [2] illustrates a simplified view of the main immune recognition and activation mechanism. Phase (I) from the figure shows that whenever any non self antigen entered the body, antigen-presenting cell (APC) circulate throughout the body ingesting and digesting the antigen. If this antigen still cannot fully recognized at this stage, T cell will need Major Histocompatibility Complex (MHC) cell to bind the molecule and present in the APC cell surface as an MHC complex (II). This MHC/peptide will presented to T cell and allow them to recognize different MHC complex (III). After that, T cell will activated, divide and secrete a chemical signal (lymphokines) to stimulate the further action (IV). Meanwhile, B cell has a receptor with ability to recognize antigen without MHC (V). Whenever B cell receive any signal, it will be activated and will perform proliferate and differentiation process to produce plasma cells in high volumes (VI). It contains antibody that be used to neutralized the panthogen (VII). Some of these T cell and B cell will differentiate into memory cells. Taken as a whole of this process, it is the miracle of immune system and being the soldiers to defense our body from any virus entered.

![Figure 1: Simplified view of the main immune recognition and activation mechanism](image)
A. Primary and Secondary Response

The immune system has two types of response: 1) primary and 2) secondary. The primary response occurs when the immune system encounters an antigen for the first time and reacts against it by producing antibodies. The immune system learns about the antigen and thus prepares the body against any further invasion of that antigen. This learning mechanism creates what is called the immunological memory. The secondary response occurs when the immune system encounters an antigen against which it has reacted before. It is characterized by a shorter lag phase, a higher rate of antibody production, and longer persistence of antibody synthesis since the immune system already has all the information on the antigen from the immunological memory. There are two ways by which the memory is achieved in the immune system. The most widely held view uses the concept of “virgin” B-cells being stimulated by antigen and producing memory cells and effector cells [5].

AIS learns the dynamic self, produces the detectors and does the detection using four AIS concepts: “virtual thymus”, “clustering”, “danger signal” and “memory detectors” [6].

1. Virtual Thymus

“Virtual Thymus” (VT) is a novel concept. It uses observed antigens and generated DSs (the concept of the DS is defined below) and continuously provides self antigen examples that represent the dynamic self of the protected system. It solves the problem of learning a changing self and eliminates the need for a preliminary training in a protected environment. Apart from the negative selection, the way our VT works does not have analog in the existing theories of the HIS. It is important to mention that it is not yet clear to the immunologists how the repertoire of the antigens presented in the thymus during negative selection is formed.

2. Clustering

Clustering is also a novel concept that it maps matches between the detectors and antigens into the detection decisions in a way that constrains false-positive detection probability and minimizes the time until detection under this constraint. The term clustering comes from immunology, where it denotes grouping of matches between antibodies and antigens that is required for recognition of a pathogen.

3. Danger Signal

The Danger Signal (DS) is generated when there is damage to the protected system. It correlates the damage with the antigens that are in some sense close to the damage, showing that these antigens might be the cause for the damage. DS is used as a control mechanism for the detection and clonal selection, with the aim to decrease the false positives, which is already proposed but not implemented in the existing AISs. This use of the DS, and the way how it is generated is analogous to the DS and Antigen Presenting Cells (APC) in Matzinger’s model [7] of the HIS. DS to implement VT, which is a novel use of the DS. We have to mention that this use of the DS doesn’t have its analog in the existing theories and models of the HIS.

4. Memory Detectors

The detectors that prove useful in the detection undergo the clonal selection process and become memory. They provide a fast response to the already experienced nonself. Clonal selection and memory detectors are well investigated in the related literature [8].
II. AIS BASED ALGORITHMS

The immune system possesses several properties such as self/nonself discrimination immunological memory, positive/negative selection, immunological network, clonal selection and learning which performs complex tasks.

a. Immune Networks

The first idea of using immunological mechanisms in computer problems was propounded in 1986 by Farmer et al. [4]. Inspired by the immune network theory, they presented an adaptive model for the immune system. They modeled the dynamic behavior of the immune system using a set of differential equations and showed that they can be applied to learning problems effectively. Immune networks model observed emergent intelligent properties of the immune system: learning and memory. The model describes that in the absence of foreign antigen, the system activity have interactions with itself which from behavior such as tolerance and memory emerge. The premise of immune network theory is that any lymphocyte receptor within an organism can be recognized by a subset of the total receptor repertoire. The receptors of this recognizing set have their own recognizing set and so on, thus an immune network of interactions is formed. This algorithm focuses on the network graph structures involved where antibodies represent the nodes and the training algorithm involves growing or pruning edges between the nodes based on affinity (similarity in the problems representation space). That’s why immune network algorithms can use in clustering, data visualization, control, and optimization domains, and share properties with artificial neural networks [9].

b. Clonal Selection Theory

In order to explain how an immune response is mounted when a nonself antigenic pattern is recognized by a B cell, clonal selection theory is been developed [10]. When a B-cell receptor recognizes a nonself antigen with a certain affinity, it is selected to proliferate and produce antibodies in high volumes. The antibodies are soluble forms of the B-cell receptors that are released from the B-cell surface to cope with the invading nonself antigen. Antibodies bind to antigens leading to their eventual elimination by other immune cells. Proliferation in the case of immune cells is asexual, a mitotic process; the cells divide themselves. During reproduction, the B-cell clones undergo a hyper mutation process that, the Ag stimulates the B cell to proliferate and mature into terminal Ab secreting cells, named plasma cells. The process of cell division generates a clone. In addition to proliferating and differentiating into plasma cells, the activated B cells with high antigenic affinities are selected to become memory cells with long life spans. These memory cells circulate through the blood, lymph, and tissues. When exposed to a second antigenic stimulus, commence to differentiate into plasma cells capable of producing high-affinity Ab’s, preselected for the specific Ag that had stimulated the primary response, Figure 2 illustrates the clonal selection, expansion, and affinity maturation processes.

![Figure 2: Clonal selection principle [10]](image-url)
Clonal Selection Algorithm

L.N.De Castro, F.J. Von zuben developed the Clonal Selection Algorithm on the basis of clonal selection theory of the immune system [11]. It was proved that can perform pattern recognition and adapt to solve multimodal optimization tasks. The CLONALG algorithm can be described as follows:

1. Randomly initialize a population of individual(M);
2. For each pattern of P, present it to the population M and determine its affinity with each element of the population M;
3. Select n of the best highest affinity elements of M and generate copies of these individuals proportionally to their affinity with the antigen. The higher the affinity, the higher the number of copies, and vice-versa;
4. Mutate all these copies with a rate proportional to their affinity with the input pattern: the higher the affinity, the smaller the mutation rate;
5. Add these mutated individuals to the population M and reselect m of these maturated individuals to be kept as memories of the systems;
6. Repeat steps 2 to 5 until a certain criterion is met.

c. Affinity Maturation

When an antibody on the surface of a B-cell binds to an antigen, the B-cell becomes stimulated [12]. The level of stimulation depends on not only how well it matches the antigen but also how it matches other B-cells in the immune network. If the stimulation level rises above a given threshold, the B-cell will start replicating itself, producing clones of itself. An important aspect of this cloning process is that it does not produce exact clones. The offsprings that are produced by this cloning process are mutated. The newly mutated cells may have a better match for the antigen and will thus proliferate and survive longer than existing B-cells. By repeating the processes of mutation and selection, the immune system learns to produce better matches for the antigen. Alternatively, if the stimulation level is below a given threshold, the B-cell will not replicate, and in time, it will die off. This whole process of mutation and selection is called affinity maturation [5].

d. Negative Selection

The concept of a negative signal following certain lymphocyte-antigen interactions, allows for the control of those lymphocytes being anti-self [13]. Negative selection of a lymphocyte describes the process whereby a lymphocyte-antigen interaction results in the death or anergy of that lymphocyte. The immune cell is simply purged from the repertoire. Location plays a role in negative selection: the primary lymphoid organs are designed to largely exclude foreign antigens and to preserve the self-antigens, whereas the secondary lymphoid organs are designed to filter out and concentrate foreign material, and to promote co-stimulatory intercellular immune reactions [14].

The negative selection of T-cells has been broadly used by the AIS community as a model to perform anomaly detection. Basically, the negative selection of T-cells that occurs within the thymus is based on the following considerations. The thymus is comprised of a myriad of molecules that primarily present self-molecules to the naïve T-cells (immature T-cells just produced and with no function yet). The interactions of immature T-cells with the self molecules results in the death of all those naïve T-cells that recognize the self-molecules. This means that only T-cells that do not recognize self-molecules are allowed to survive and become functional T-cells.
e. Dendritic Cell Algorithms
The Dendritic Cell Algorithm (DCA) is an example of an immune inspired algorithm
developed using a multi-scale approach. This algorithm is based on an abstract model of dendritic
cells (DCs). The DCA is abstracted and implemented through a process of examining and modeling
various aspects of DC function, from the molecular networks present within the cell to the behavior
exhibited by a population of cells as a whole. Within the DCA information is granulated at different
layers, achieved through multi-scale processing.[15]

III. CONCLUSION
A miracle of our body, an Immune System (IS) prevents the enemy cells, such as bacteria or
viruses, from entering the body. This biological IS has intelligent capabilities of detecting or
recognizing self/non-self antigen in the body. Artificial Immune Systems (AIS) is one of the recent
biologically inspired approaches to emerge from computer science, possess nonlinear classification
properties along with biological properties such as self/non-self identification, Negative Selection
and Clonal Selection. This overview in general attempts to bring out the capabilities of AIS and also
reviewed on various AIS algorithms.

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