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ARTIFICIAL IMMUNE SYSTEM: INTELLIGENT SYSTEMS INSPIRED BY THE HUMAN IMMUNE SYSTEM

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ABSTRACT

Artificial Immune System(AIS) are intelligent computational systems evolved using theories of the human immune system. Our immune system is naturally self organising and adaptive. It has continually inspired the computational research especially as the problems are getting more intricate. Different perspectives can help build solution for complex problems pertaining to machine learning, classification, anomaly detection. This overview undertakes the exploration of the remarkable features of the human system that is motivating the researchers to build Artificial Immune System based intelligent classification models. It's a promising area providing substantial diversity.

Keywords: *Immune System, Diversity, Clonal Selection, Antigens, Memory, Small Dataset.*

Introduction

Natural systems have been the source of motivation for the various computational algorithms. Most of these algorithms are inspired by the dynamic learning mechanism of the human system. One such example is Artificial Immune System (AIS) which is inspired from the biological immune system. Both Artificial Immune Systems (AIS) and Genetic Algorithms (GA) are adaptations of Evolutionary Methodology. Both maintain diversity and also use mutation to generate the progeny. Genetic Algorithms evolve their populations using crossover and mutation whereas AIS uses an asexual prototype. AIS based classification algorithm was proposed by Watkins et al. [1]. The goal of the system is to develop the memory cells (Feature Vector) by using the evolutionary artificial mechanism which can be utilized for many tasks such as classification. There are various application areas [2], [3] where AIS has been applied successfully. AIS applications include recognition, classification, clustering, anomaly detection and optimization both combinatorial and continuous [4]. An intelligent classification approach inspired by AIS is proposed in [5] using fuzzy cognitive map learning. FCM analyses and depicts a system as perceived by a human. The technique generates a conceptual model which does not require exact measurements and values and hence is used for unstructured information in imprecise formats.

Some significant AIS systems are built on the concepts of Clonal Selection [6], Immune Network [7] and Negative Selection [8]. Negative Selection removes the self recognizing elements and has found applications in areas like Fault detection, Network Security, Intrusion Detection etc. The Immune Network Theory found wide use in data mining and clustering but unfortunately has fallen out of favour with immunologists. The basic adaptive response of the immune system is described by the Clonal Selection (CS) process. The best matched cells proliferate and get selected over those which do not recognize the antigens. Clonal Selection was used in varied applications such as document classification, time series forecasting, automated scheduling and various types of pattern recognition.

Optimization, generalization, noise tolerance, diversity generation, learning and pattern recognition are some of the tasks undertaken by AIS in the recent research. These flexible non linear models are capable of taking the challenges of complex real world data. Analogous to NN and GA, AIS is an intelligent mechanism for many applications in diverse domains. The [9] presents a study of various

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AIS algorithms and their various applications. Artificial immune system learning is being explored for new classification schemes. The intelligent AIS based approach using fuzzy cognitive map learning is explored in [5] and the algorithm so proposed is implemented in some well established machine learning datasets. Since AIS imitates the human immune system hence highlighting the main theory behind it is imperative.

Human Immune System

Human Immune System's (HIS) efficient capabilities such as:

- self organizing memory,
- recognition characteristics of an invading pathogen,
- capabilities of memorizing a pattern,
- learning from examples,
- structures with multilayer,
- capability to adapt
- ability to remember, classify and nullify the foreign element

are among some very interesting and inspiring phenomenon for pattern recognition researchers and have led to new developments in Computational Intelligence.

Living organisms are constantly exposed to a multitude of disease ausing viruses and microorganisms called 'pathogens'. The vertebrates are the advanced organisms and have an efficient mechanism of protection against the invaders [10]. Biological immune system defends the organism against the antigens (Foreign invader/substance/pathogens). It is an intricate web of complex cells, organs and tissues [11]. Antigens are the pathogens that trigger specific responses of the immune system. Once stimulated the immune system generates antibodies to attack the invading antigen. Our immune system has the set of B-cells that produce antibodies. A very specific antibody is made by each B-Cell which is constituted from the genes. These B-cells with varied receptive shape bind with the particular antigen in order to eliminate it.

The problems occurs as the gene library do not have genes that characterize antibodies for every antigen conceivable. So, to tackle the antigens whose proper gene is not present, our immune system's dynamic process allows the gene in the gene library to produce a huge diverse range of antibodies by arbitrarily combining and recombining. The process is depicted in Figure 1. This aids the immune system to create the specific antibody for the particular antigen the body may be encountering for the first time.

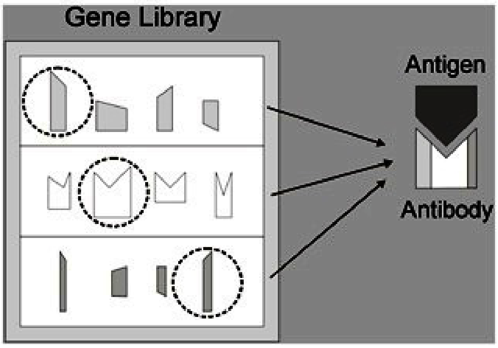

Fig. 1: Natural Process of Antibody Creation

Gene selection is based on the Clonal Selection Principle [12]. All gene fragments are not used to generate the desired gene. Clonal selection principle states that only those cells get selected and proliferate that recognize the antigen. The best fit B-cells snowball and make many Clones. These mutate rapidly to generate the desired gene. Here when an antigen attacks, the system searches its existing set of gene fragments in the gene library. If found then good but if there is absence of a gene that can properly fit with the antigen then based on the clonal selection principle the best fit genes from the library showing the maximum affinity are chosen. They randomly combine and recombine to produce a number of new gene combinations and the best fit amongst them are chosen to bind the antigen.

The immune system is a multilayer defence system [13]. The two main layers are:

- **Innate Immunity**: This is the immunity that gets transferred from a mother to the offspring, a kind of immunity that we are born with. It is associated with non specific responses and adapts or changes with respect to pathogens. These includes processes to make living conditions difficult for invading pathogens or create an inflammatory response to activate cytokines which are hormone like messengers. It is akin to a first initial line of protection or defence giving time to the adaptive system to come up with more specific response at the same time keeping a check on the infection.
- **Adaptive Immunity**: This is the acquired immunity that specifically recognizes and eliminates invading organisms selectively. It is so called as it learns and adapts to identify the attacking pathogen. It additionally memorizes this learning for future use making subsequent responses to the same pathogen quicker. Primary response to a pathogen encountered for the first time is when the learning occurs and is a slow process. It can take upto three weeks to clear infection. But a subsequent attack by the same pathogen, which is now learnt and put in the immunological memory, is countered with a more efficient and rapid secondary response as the immune system recognized the pathogen. Each antibody cell has a paratope and idiotope for recognition, Figure 2. The chemical bonds are formed between receptors of the immune cells and epitopes located on the pathogens which indicates recognition or detection. The strength of these bonds is called affinity.

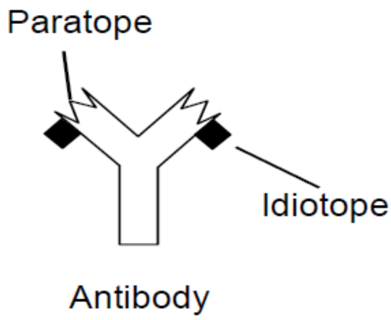

Fig. 2: Paratope and Idiotope on Antibody

The main characteristics of Adaptive immunity are:

- **Antigen Distinction Capability:** It is the ability to recognize the subtle differences between antigens and hence distinguish them.
- **Diversity:** The adaptive human immune system generates millions and millions of different antibodies capable of recognizing different known and unknown structures known as pathogens.
- **Immunological memory:** Each encounter with a pathogen is stored in memory for future references. Every encounter after the first one are met with quicker and stronger response.
- **Self and Non self Identification:** This is the ability of the immune cells to distinguish between self and foreign pathogens. This is significant as self should not be the target for destruction.

The Adaptive Immunity works together with Innate Immunity to destroy the foreign non self pathogens.

Information Processing Aspects of the Human Immune System

We enumerate some interesting capabilities of the immune system which are analogous to information processing

- **Pattern Matching:** The ability of the antibodies to recognize specific antigens and generate pertinent reactions indicates a sophisticated mechanism of learning, recognition and matching.
- **Feature Extraction:** Antibodies bind themselves to parts of antigen, Figure 1. Adept capability of our Immune System to recognise the antigen by matching process.
- **Learning and Memory:** The immune system learns adaptively through the various interactions with the different antigens over time. If and when the same antigen attacks again, the system combats with a quicker and more intense reaction.

- **Diversity:** Clonal Selection constantly explores newer and varied configurations aspiring for better fits with antigens. Mutation and Crossover aids in exploration and in generating new and promising progeny.
- **Distributed Processing:** The immune system unlike the nervous system lacks a central control unit. Detecting an antigen and responding to it is a completely local cycle of execution. This distributed and decentralised yet collaborative behaviour is exhibited by all the immune cells.
- **Self-Regulation:** The seriousness and strength of an attack determines the immune system response from mild to strong. The cells regulate themselves automatically once the attacking antigens are decimated.
- **Self-Protection:** The immune system protects itself while safeguarding the entire body.

There is no other system for maintaining and protecting the immune system. The efficient and unique mechanisms of biological immune systems have inspired a class of computational intelligence called Artificial Immune Systems. The typical AIS models and algorithms provide robust capabilities of information processing imitating the features of immune system.

Artificial Immune System: Algorithms and Uses

The earlier section mentioned some of the human immune system characteristics which can be beneficial for building intelligent frameworks. Artificial Immune Systems (AIS) is the study and design of such systems implementing one or more of the remarkable properties of pattern recognition, learning, memory and has always been of interest [14]. It specifically deals with the development and study of pertinent computational abstractions of the biological immune system. In the past many AIS, Artificial Immune System, have evolved inspired by the biological process. [15], [16], [17]. Four main categories of AIS algorithms are found in literature

- **Immune Network Model:** This theory proposed by Jerne [18] says that a idiotypic network of cells which are interconnected is maintained by the immune system for recognition of the antigens. The network is stabilized by suppressing and /or stimulating the cells in certain specific ways. Antibody bonding with antibody and with antigen respectively are significant for the network formation. Two cells are considered connected if the affinity between them is above a threshold and the connection strength is proportional to the value of the score of the affinity.
- **Negative Selection Algorithm:** Negative Selection deals with protecting the self yet have the ability to detect antigens even the new ones. The objective is to impart forbearance for self-cells. The algorithm was given by Forest et al [19] and been used for applications like intrusion detection [20].
- **Danger Theory:** This concept was introduced by Matzinger [21]. To prevent autoimmune self-destructive behaviour, only the right and appropriate cells be matched. The human immune system also triggers a response when it encounters something foreign and not like self. This differentiation is learnt as soon as life begins in the body.
- **Clonal Selection Algorithm:** The Clonal Selection Algorithm, CLONALG, by Castro [22], [23], [6] substantiates that clonal selection theory can help in pattern recognition. It helps to recognize and distinguish not only between self and non self but many different categories of patterns. In the process, the mutation and crossover help generate additional data. Our framework is inspired by this mechanism of the artificial immune system. The CLONALG is summarized as follows:
- Initialize a random population of antibody set and memory cell set (M) from the training sample data.
- Select a memory cell/sample antigen/pattern (P) from the population (M) and for each memory cell in the population M the affinity is determined and the top n best highest affinity memory cells are chosen.
- **Clone Generation Step**: Generate copies/clones of selected memory cells. The number of the clones generated is directly proportional to the affinity of selected memory cells with the antigen. The higher the affinity, the higher the number of clones, and vice-versa.
- **Mutation Step**: Mutation of the clone memory cell is done subsequently. The rate of change in the clone is inversely proportional to the affinity of selected memory cells with the antigen. The process of mutation and/or crossover to achieve this is shown in Figure 3. Crossover exchanges

the gene data between two selected parents. The objective is to boost the diversity in two offspring progeny. Mutation randomly modifies an offspring. The intention is to prevent a local maxima by not allowing all solutions to fall into a localized optimum. Mutation can take place before or after crossover

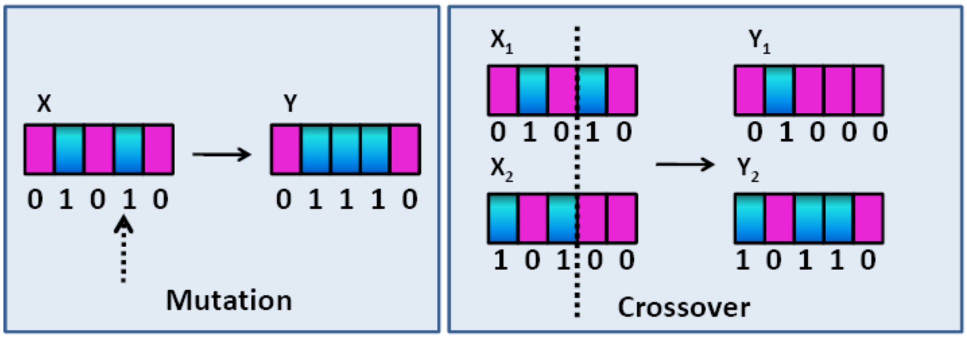

Fig. 3: An instance Showing Mutation and Crossover

Add only those newly generated cells after mutation which can recognize the sample antigen to the initial population M of antibody set. Control the size of the antibody set using a stopping criteria. Figure 4 shows the clonal selection process:

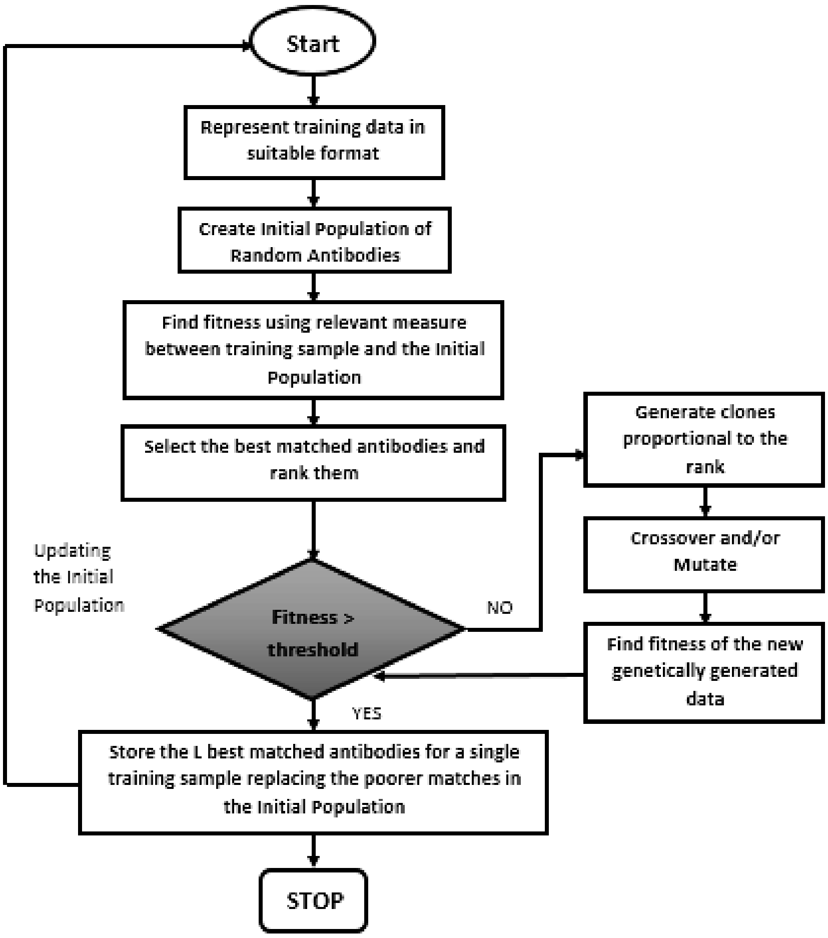

Fig. 4: Flow Diagram of Clonal Selection

Repeat steps (b) to (e) until all patterns in memory cells (M) are processed.

Applications of AIS

Two computational meta-heuristic algorithms Genetic algorithms and AIS are inspired respectively from genetics mechanism and theoretical immunology. Genetic Algorithm are based on the natural evolution process driven by competition amongst members of specific species whereas AIS are inspired by a different mechanism of nature preconceived to protect a living organism against intruding viruses and bacteria. Obviously the focus of GA is on one particular optimal and that is the most favourable solution. On the other hand AIS are multi focussed and more flexible as they deal with forever changing intruders. This particular capability of AIS can be explored for optimization problems. The salient and critical interest of our requirement in Diversity is actually implemented directly in the basic structure of the AIS algorithm and is not instituted in the genetic algorithms.

AIS is proven to be more reliable and robust though a little slower than the Genetic Algorithms. This is because the AIS explore its domain more thoroughly at the cost of a unrushed convergence to a optimal point. Though AIS are slow but the unhurried process helps AIS in detecting higher quantity of optimal regions. In GA the pressure of selection prevents the algorithm from finding other optima points particularly if these points lie in close vicinity of each other. CSA shows a clear superiority for multimodal as well as unimodal functions. Mutation rates for the two algorithms are different where CSA is driven mainly by mutation and GA consider both mutation and crossover.

Artificial Immune System has caught the attention of researchers in recent years due to their wide applicability to many different applications and fields [9]. Algorithms inspired from AIS are used for data analysis, prediction and classification. The AIS community has been active for quite some time now. The research has been prolific not only modelling the immune systems but also encompassing applications from the real world based on diverse algorithms inspired by these systems. A review of AIS approach based current applications are given in [24]. It presents a survey of applications of AIS. Some significant applications of AIS based modelling areas are as follows:

- Sensor network [25]
- Computer security[26]
- Optimization problem [22],[27]
- Design and intrusion detection [28],[29]
- Design of recommendation system [30],[31]
- Pattern recognition [32]
- Clustering/Classification[24]

The special characteristic of AIS mechanisms like memory, learning, discrimination, self/ non self, uniqueness make it very pertinent for the field of pattern recognition. Both Negative selection and Clonal selection theories are equally powerful for the AIS based designs and models. The application area determines the most appropriate theory that should be considered by the designer [24]

Conclusion

Optimization, generalization, noise tolerance, diversity generation, learning and pattern recognition are some of the tasks undertaken by AIS. These flexible non linear models are capable of taking the challenges of complex real world data. Analogous to NN and GA, AIS is an intelligent mechanism for many applications in diverse domains. The [9] presents a study of various AIS algorithms and their applications. CLONALG based on Clonal Selection Principle is one of the popular models of Artificial Immune System. It has been proposed by many researchers for successful pattern recognition and optimization. We have given a brief outline of this algorithm in this work. Shaojin proposed classification based on AIS [33]. Representation of data is very crucial for any classification. The efficiency of any classifier largely depends not only on the properties of the classifier but how well the data is represented. The representation learning or feature learning of data is a set of optimal techniques capable of learning the feature i.e raw data transformed to a representation that can be utilized and exploited effectively by a task. Extracting the best optimal feature is very significant for classification tasks. This is motivated by the fact that tasks need input representations that are computationally and mathematically appropriate as well as easy to process. Unfortunately the data from real world like personal photographs are highly variable, complex and sometimes redundant. Hence it is imperative to ascertain and exploit gainful and productive representations or features from raw data. AIS can be a significant tool in extracting gainful features for small datastets.

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