Chapter 2

Literature Review

Recently researchers have begun to argue that intelligent behavior and cognition are much more about effective interaction between agent and environment, rather than an agent's capability to handle abstract world models internally. Based on these influences the field of behavior-oriented AI has emerged, which unlike its traditional counter part, is mainly concerned with the study of *autonomous agent*s, situated in and interacting with an environment. Typical criticisms of conventional artificial intelligent systems are that these systems show brittleness for environmental changes, and required much computing time for mapping complex sensory inputs into complex internal models before action can be taken. Therefore, in recent years much attention has been focused on the *reactive planning* systems (e.g., behavior-based Al), which have demonstrated robustness and flexibility against dynamically changing world. On the other hand, biological information processing systems have many interesting functions and are expected to provide various feasible ideas to engineering fields, especially robotics. Biological information processing systems in living organisms can be mainly classified into the following four systems: (1) *brain-nervous system,* (2) *genetic system,* (3) *endocrine system,* and (4) *immune system* [17].

Nervous and genetic systems have already been applied to engineering fields by modeling as neural networks, and genetic algorithms, and they have been widely used in various fields. Immune system, in particular, have various interesting features such as immunological memory, immunological tolerance, micro-pattern recognition, non-hierarchical distributed structure, and so on that can be applied to many engineering fields. In the following lines we will brief some of the basic features of the immune system.

- **Recognition:** The immune system can recognize and classify different patterns and generate selective responses. Recognition is achieved by intercellular binding the extent of this binding is determined by molecular shape and electrostatic charge. Self-non-self discrimination is one of the main tasks of the immune system deals with during the recognition process.

- **Feature Extraction:** Antigen Presenting Cells (APCs) interpret the antigenic context and extract its features, by processing and presenting antigenic peptides on its surface. These APC servers as a filter and a lens: a filter that destroy molecular noise, and a lens that focuses the attention of the lymphocyte receptors.

- **Diversity:** It uses combinatorics, usually done by a genetic process for generating a diverse set of lymphocyte receptors to ensure that at least some lymphocytes can bind to any known, or unknown antigen.

- **Learning:** It learns, by experience, the structure of a specific antigen. Changing Lymphocyte concentration is the mechanism for learning and takes place during the primary response of Ag interception. So the learning ability of the immune system lies primarily in the mechanism which generates new immune cells on the basis of the current state of the system (also called *clonal selection mechanism).*

- **Memory:** When lymphocytes are activated, a few of each kind become special memory cells which are content-addressable, and continues to circulate in the blood. The life time of immune memory cells is dynamic and requires stimulation by antigens. The immune system keeps an ideal balance between economy and performance in conserving a minimal but sufficient memory of the past, and this is done normally by using short-term and long-term memory mechanisms.

- *Distributed Detection:* The immune system is inherently distributed. The immune cells, in particular lymphocytes, circulate through the blood, lymph, lymphoid organs, and tissue spaces. As lymphocytes recirculate, if they encounter antigenic attacks ,they stimulate specific immune responses.

- *Self-regulation:* The basic mechanisms of immune responses are self-regulatory in nature. There is no central organ that controls the functions of the immune system. The regulation of immune responses can be either local or systemic, depending on the route and property of the antigenic challenge.

- *Co-stimulation:* Activation of B cells are closely regulated through co-stimulation. The second signal coming from helper T cells helps to ensure tolerance and judge the invader is dangerous, harmless, or false alarm.

- *Dynamic protection:* Clonal expansion and somatic hyper-mutation allow generation of high-affinity immune cells which are called affinity maturation. This process dynamically balances exploration versus exploitation in adaptive immunity . Dynamic protection increases the coverage provided by the immune system over time.

There are other features like adaptability, specificity, self-tolerance, differentiation etc. , and they perform important functions in immune response. All these remarkable information-processing properties of the immune system can be utilized several important aspects in the field of computation. Recent studies have clarified that the immune system does not only detect and eliminate the non-self materials, but plays important roles to maintain its own system against dynamically changing environments. Therefore, immune system would provide a new paradigm that is suitable for dynamic problem dealing with unknown environments rather than static problem. However, the immune system has little been applied to engineering fields in spite of its productive characteristics. In the following sections we will scan some of the applications in the literature on the immune system. Then we will elaborate to our research, and its importance.

1. Computer Security

There are many problems encountered while trying to apply computer security, such activities as detecting unauthorized use of computer facilities, keeping the integrity of data files, and preventing the spread of computer viruses. *Forrest et al* viewed these protection problems as instances of the more general problem of distinguishing *self* as legitimate users, corrupted data, etc., and from *non-self* as unauthorized users, viruses, etc. They introduce a change-detection algorithm that is based on the way that natural immune systems distinguish self from other. Mathematical analysis of the expected behavior of the algorithm allows them to predict the conditions under which it is likely to perform reasonably. Based on this analysis, they also reported preliminary results illustrating the feasibility of the approach on the problem of detecting computer viruses. They demonstrate that the algorithm can be practically applied remains an open problem, and finally, they suggest that the general principles can be readily applied to other computer security problems [18].

Kephart et al anticipated that with in the next few years, the Internet will provide a rich medium for new breeds of computer viruses capable of spreading faster than today's viruses. To counter this threat, They have developed an immune system for computers that senses the presence of a previously unknown virus, and within minutes automatically derives and deploys a prescription for detecting and removing it to other PC's in the network. Their system was integrated with a commercial anti-virus product, IBM Anti-Virus [19].

Their immune system algorithm consists of the following steps:

1. Discovering a previously unknown virus on a user's computer.
2. Capturing a sample of the virus and sending it to a central computer.
3. Analyzing the virus automatically to derive a prescription for detecting and removing it from any host object.
4. Delivering the prescription to the user's computer, incorporating it into the anti-virus data files, and running the anti-virus product to detect and remove all occurrences of the virus.

5. Disseminating the prescription to other computers in the user's locale and to the rest of the world.

Dasgupta et al Conducted a research that focuses on investigating immunological principles in designing a multi-agent system for intrusion detection and response in networked computers. In this approach, the immunity-based agents roam around the machines (nodes or routers), and look for changes such as malfunctions, faults, abnormalities, misuse, deviations, intrusions, etc. These agents can mutually recognize each other's activities and can take appropriate actions according to the underlying security policies. Their activities are coordinated in a hierarchical fashion while sensing, communicating and generating responses. Such an agent can learn and adapt to its environment dynamically and can detect both known and unknown intrusions. Their research is the part of an effort to develop a multi-agent detection system that can simultaneously monitor networked computer's activities at different levels (such as user level, system level, process level and packet level) in order to determine intrusions and anomalies. Their proposed intrusion detection system is designed to be flexible, extendible, and adaptable that can perform real-time monitoring in accordance with the needs and preferences of network administrators [20].

2. Anomaly Detection in Time Series Data

Detecting anomalies in time series data is a problem of great practical interest in many manufacturing and signal processing applications. *Dasgupta et al* presented a novel detection algorithm inspired by the negative-selection mechanism of the immune system, which discriminates between *self* and *non-self*. Self is defined to be normal data patterns and non-self is any deviation exceeding an allowable variation. Experiments with this novelty detection algorithm are reported for two data sets: simulated cutting dynamics in a milling operation and a synthetic signal. The results of the experiments exhibiting the performance of the algorithm in detecting novel patterns were reported [21].

Anomaly detection in a system or a process behavior is very important in many real-world applications such as manufacturing, monitoring, signal processing etc. *Dasgupta et al* presented an anomaly detection algorithm inspired by the negative-selection mechanism of the immune system, which discriminates between *self* and *other*. Here self is defined to be *normal data patterns* and non-self is any deviation exceeding an allowable variation. Experiments with this anomaly detection algorithm are reported for two data sets: time series data, generated using the Mackey-Glass equation and a simulated signal. Compared to existing methods, this method has the advantage of not requiring prior knowledge about all possible failure modes of the monitored system. Results are reported to display the performance of the detection algorithm [22].

Ishida et el proposed a new information processing architecture which is extracted from the immune system. By focusing on informational features of the immune system (i.e. specificity, diversity, tolerance, and memory), an immune algorithm is proposed. The algorithm proceeds in three steps: diversity generation, establishment of self-tolerance, and memorizing non-self. The algorithm may be used to model the system by distributing agents. In this case, the system (the self) as well as the environment (the non-self) are unknown or cannot be modeled. Agent-based architecture based on the local memory hypothesis and network- based architecture based on the network hypothesis is discussed. Agent-based architecture elaborated with the application to adaptive system where the knowledge about environment is not available. Adaptive noise neutralizer is formalized and simulated for a simple plant [23].

D'haeseleer et al presented a new achievements on a distributable change-detection method inspired by the natural immune system. A weakness in the original algorithm was the exponential cost of generating detectors. Two detector-generating algorithms are introduced which run in linear time. The algorithms are analyzed, heuristics are given for setting parameters based on the analysis, and the presence of holes in detector space is examined. The analysis provides a basis for assessing the practicality of the algorithms in specific settings, and some of the implications are discussed [24].

3. Fault Diagnosis

The body's immune system is impressively good at coping with external and internal errors, usually known as bacteria and viruses. The body is able to distinguish the haemoglobin found in blood from the insulin secreted by the pancreas from the vitreous humor contained in the eye from everything else. It must manage to repel innumerable different kinds of invading organisms and yet not attack the body. *Tyrell* posed a question which is "can we mimic these mechanisms in the design of our computer systems?". He gave some details on how the body actually performs this amazing feat and gives some suggestions as to how this might inspire the design of computer systems increasing their reliability [25].

Braddly et al proposed a novel approach to hardware fault tolerance that takes inspiration from the human immune system as a method of fault detection and removal. The immune system has inspired work within the areas of virus protection and pattern recognition yet its application to hardware fault tolerance is untouched. Their paper introduces many of the ingenious methods provided by the immune system to provide reliable operation and suggests how such concepts can inspire novel methods of providing fault tolerance in the design of state machine hardware systems. Through a process of self/non-self recognition the proposed hardware immune system will learn to differentiate between acceptable and abnormal states and transitions within the immunized system. Potential faults can then be agged and suitable recovery methods are invoked to return the system to a safe state [26].

A production line of semiconductor is a large scale and a complex system. A control system of the line is considered to be difficult to control because there exist lots of malfunctions such as maintenance of equipment, equipment break down disturbance in the production of wafers in the semiconductor production system. *Fukuda et al* have been exploited some methods and systems using simulations or expert systems approach to solve these disturbances. The semiconductor production systems had been large and complex and the environments of the systems have been changing dynamically, so that it is hard to exploit a perfect control system of semiconductor production by using only conventional methods.

31

Their paper presents a method applying an artificial immunity based system described by multi agent nets to adapt itself to a dynamically changing environment [27].

Research conducted by *Ishiguro et al* did focused on chemical and nuclear plant. In these systems, once a certain device (unit) in a plant system becomes faulty, its influence propagates through the whole system, and then causes a fatal situation. To enhance safety and reliability of plant systems, an efficient fault diagnosis technique is desired. On the other hand, biological systems such as human beings can be said to be the ultimate information processing system, and are expected to provide feasible ideas to engineering fields. Among the information processing systems in biological systems, immune systems work as on-line fault diagnosis systems by constructing large-scale networks, called immune networks (idiotypic networks). In this study, the researchers tried to apply these immune networks to fault diagnosis of plant systems, and the feasibility of their proposed method is confirmed by simulations [28].

4. Pattern Recognition

Forrest et al described an immune system model based on binary strings. The purpose of the model is to study the pattern recognition processes and learning that take place at both individual and species levels in the immune system. Genetic algorithm is a central component of their model. The paper reports simulation experiments on two pattern recognition problems that are relevant to natural immune systems. Finally, it reviews the relation between the model and explicit fitness sharing techniques for genetic algorithms, showing that the immune system model implements a form of implicit fitness sharing [29].

Dasgupta et al described a technique based on immunological principle, for a novel pattern detection method. it is a probabilistic method that uses a negative *sele*ction scheme, complement pattern space, to detect any change in the normal behavior of monitored data patterns. The technique is compared with a positive selection approach, Implemented by an ART neural network, which uses the self pattern apace for anomaly detection [30].

Hunt et al described an artificial immune system (AIS) which is based upon models from the natural immune system. This natural system is an example of an evolutionary learning mechanism which possesses a content addressable memory and the ability to forget little used information. It is also an example of an adaptive non-linear network in which control is decentralized and problem processing is efficient and effective. As such, the immune system has the potential to offer novel problem solving methods. The AIS is an example of a system developed around the current understanding of the immune system. It illustrates how an artificial immune system can capture the basic elements of the immune system and exhibit some of its chief characteristics. They illustrate the potential of the AIS on a simple pattern recognition problem. Then, they apply the AIS to a real-world problem: the recognition of promoters in DNA sequences. The results obtained are consistent with other approaches, such as neural networks and are better than the nearest neighbor algorithm. They concluded that the primary advantages of the AIS are that it only requires positive examples, and the patterns it has learnt can be explicitly examined. In addition, because it is self-organizing, it does not require effort to optimize any system parameters [31].

Cooke et al have developed an artificial immune system AIS which is based on the human immune system. The AIS possesses an adaptive learning mechanism which enables antibodies to be used for classification tasks. In their paper, they described how the AIS has been used to evolve antibodies which can classify promoter containing and promoter negative DNA sequences. The DNA sequences used for teaching were 57 nucleotides in length and contained procaryotic promoters. Their system classified previously unseen DNA sequences with an accuracy of approximately 90% [32].

5. Autonomous Agents

In recent years much attention has been focused on behavior-based artificial intelligence, (Al) which has already demonstrated its robustness and flexibility against dynamically changing world. *Watanabe et al* developed an approach in which the followings problems have not yet been tackled: 1) how to construct an appropriate arbitration mechanism, and

2) how to prepare appropriate competence modules (behavior primitives). One of the promising approaches to tackle the problems is a biologically inspired approach. The Watanabe group focused on the immune system, since it is dedicated to self-preservation under hostile environment, based on the fact that autonomous mobile robots must cope with dynamically changing environment. They constructed a new decentralized behavior arbitration mechanism inspired by the biological immune system. Then, they applied it to the garbage-collecting problem of autonomous mobile robot that takes into account the concept of self sufficiency. To verify the feasibility of thier method, they carried out some experiments using a real robot. In addition, they investigated two types of adaptation mechanisms to construct an appropriate artificial immune network without human intervention [33].

Immunized Computational Systems combine a *priori* knowledge with the adapting capabilities of immune systems to provide a powerful alternative to currently available techniques for intelligent control. This was the basic idea that *Krishnakumar et al* presented on various levels of intelligent control and relate them to similar functioning in human immune systems. A technique for implementing immunized computational systems as adaptive critics was presented then applied to a flight path generator for level 2, non-linear, full-envelope, intelligent aircraft control problem [34].

Conventional artificial intelligent (Al) systems have been criticized for their brittleness under hostile /dynamic changing environments. Therefore, recently much attention has been focused on the reactive planning systems such as behavior-based AI. However, in the behavior-based Al approaches, how to construct a mechanism that realizes adequate arbitration among competence modules is still an open question. *Ishigura et al* proposed a new decentralized consensus-making system inspired from the biological immune system. They applied their proposed method to a behavior arbitration of an autonomous mobile robot as a practical example. To verify the feasibility of their method, we carry out some simulations. In addition, they proposed an adaptation mechanism that can be used to construct a suitable immune network for adequate action selection [35].

Lee et al proposed a method of cooperative control (T-cell modeling) and selection of group behavior strategy (B -cell modeling) based on imnnme system *in* distributed autonomous robotic system (DARS). The immune system is a living body's self-protection and self-maintenance system. Thus these features can be applied to decision making of optimal swarm behavior in dynamically changing environment. For the purpose of applying imnnme system to DARS, a robot is regarded as a B cell, each environmental condition as an antigen, a behavior strategy as an antibody and control parameter as a T-cell respectively. The executing process of the proposed method is as follows: When the environmental condition changes, a robot selects an appropriate behavior strategy. Then, the behavior strategy is stimulated and suppressed by other robot using communication. Finally, much stimulated strategy is adopted as a swarm behavior strategy. This control scheme is based on clonal selection and idiotopic network hypothesis, and it is used for decision making of optimal swarm strategy. By T-Cell modeling, adaptation ability of robot is enhanced in dynamic environments [36].

Recently, strong demands of developing autonomous decentralized system have been arisen since systems have been increasing in their scale and complexity. On the other hand, biological system such as human beings can he said the ultimate decentralized system, and is expected to provide feasible ideas to engineering fields. Immune systems work as on-line fault diagnosis systems by constructing self-non-self recognition networks. The aforementioned ideas were the base prospect *Ishiguro, and his group* who tried to apply this immunological self-non-self recognition networks to a gait acquisition of 6-legged walking robot as a practical example [37].

Meshref, and VanLandingham proposed a paper that applies an AIS technique to a Distributed Autonomous Robotics System (DARS) problem [38]. One of the classic problems in DARS is the dog and sheep problem. In their paper they tried to benefit from the features of the natural immune system in the development of the dog and sheep problem. On the other hand, they found that Natural immune systems are sophisticated information processors. They learn to recognize relevant patterns, they remember patterns that have been seen previously, and they use diversity to promote robustness.

Furthermore, the individual cells and molecules that comprise the immune system are distributed throughout the body, encoding and controlling the system in parallel, with no central control mechanism. The immune system uses several weapons to attack the foreign antigen. Abstractly, these weapons are the helper T-cells, B-cells, and antibodies. We simulated the dog as a B cell, the sheep as an antigen, the antibody as the dog behavior, the antigen response as the sheep behavior, and the sheep-to-pen distance as a helper T cell. The system interacts in an equivalent manner similar to the immune response trying to restore the environment to its original state, which is the sheep inside the pen.

6. Motivation And Progress In The Proposed Work

During the previous sections, we went through most of the applications that benefits from most of the immune system features. We did a simulation work in our proposed research by developing an artificial immune network the behavior of three mobile robots interacting in an environment. The problem was a persuit evasion problem, where two autonomous robots act as antibodies, and the third autonomous robot acts as an antigen. Typically, the two antibody robots are trying to cancel the effect of the antigen robot.

We compared the results obtained from the conventional multiagent rule-based simulation with our AIS behavioral approach, and the results were promising; more details can be found in section nine of chapter three.

As a result of scanning the literature, and as a continuation to our work we discovered that enhancing the artificial immune network response using memory is one of the areas that needs more. Using memory as a feature in the immune system adds learning to the overall adaptive system, and guarantees quicker adaptive future responses. A group of scientists produced a couple of papers that bear comparable ideas about the acquired immunity in their research, but there was no progress in this direction [35], [39]. We believe that this novel technique can be applied to many robotics applications, where autonomous robots are required to have adaptive behavior in response to their environment.