Exploiting the Immune System for Computation

ARTIFICIAL IMMUNE SYSTEMS AT THE UNIVERSITY OF KENT

I. INTRODUCTION

Over the past five years, within The University of Kent's Computing Laboratory, a group has emerged that is investigating the natural immune system as inspiration for computation. The group has established itself as one of the world leaders in the field of Artificial Immune Systems (AIS), through their work on extracting immunological metaphors for applications in machine learning, optimisation, software testing and fault tolerance. The approach adopted is interdisciplinary, with group members that are experts in various areas of computer science, mathematics and immunology. The group at Kent has been instrumental in the establishment of the International Conference on Artificial Immune Systems (ICARIS) and a UK based academic network for AIS known as ARTIST.

The AIS group is part of the larger Applied and Interdisciplinary Informatics Group (AII) at Kent, both of which are headed by Dr. Jon Timmis. The AIS group collaborates with many industrial partners such as Sun Microsystems, Edward Jenner Institute for Vaccine Design, NCR PLC and BAE SYSTEMS, attempting to apply the AIS approach in an industrial setting.

Within the group, Jon Timmis and his team are investigating a number of avenues of research, ranging from theoretical aspects of AIS, abstraction of biologically plausible algorithms, applications of AIS technology and interactions of the immune system with neural and hormonal systems.

The immune system (IS) is a complex biological system essential for survival, which involves a variety of interacting cellular and molecular elements that control either micro- or macro-system dynamics. The strategies of the immune system are based on task distribution to obtain distributed solutions to problems with different cells able to carry out complementary tasks. Thus, cellular interactions can be envisaged as parallel and distributed processes among cells with different dynamical behavior and the resulting immune responses appear to be emergent properties of self-organising processes.

AIS can be defined as adaptive systems inspired by theoretical immunology, observed immune functions, principles and models, which are applied to problem solving. The development of AIS as a field of research has been progressing steadily over recent years. Much work has gone into the development of new algorithms inspired by the immune system for a variety of tasks, ranging from machine learning, data mining, to fault tolerance, and network intrusion detection and so on. Therefore, using immunology as a foundation, a new and exciting research field has evolved that has led to the creation of innovative applications of immune metaphors.

II. RESEARCH AT KENT

At Kent, there are a large number of people involved in AIS research. In this section we outline just some of the current research projects being undertaken within the group. This is not an exhaustive review of all themes of research currently undertaken by the group; a full list can be found at the URL at the end of this article.

A. Immunising Software

Peter May, a PhD student supervised by Prof. Keith Mander and Dr. Timmis, is developing a novel AIS based approach to software testing, in particular mutation testing. Mutation testing is an effective fault-based testing approach that uses large numbers of slightly varying versions of the program-under-test to quantify the test data's adequacy. However, the large number of "mutant" programs means this approach is computationally expensive. Peter's system aims to reduce the number of mutant programs required to ones that represent the most common errors made. Simultaneously his system will evolve high-quality test data. This co-evolutionary approach, grounded on the evolution of antibodies in the immune system, effectively gives a programming-environment specific form of mutation testing, which will hopefully reduce the computational expense associated with mutation testing.

B. Mining the Web for Interesting Pages

PhD student Andrew Secker is investigating the way immune metaphors may be employed to mine content from the web (Andrew is co supervised by Dr. Alex Freitas and Dr. Jon Timmis). Andrew's initial investigations concerned the classification of uninteresting email. At the time, this system, called AISEC, was the first email classifier to recognise that, like natural pathogens, junk email will change over time to evade standard filtering techniques. AISEC used the immune principles of constant adaptation and memory to learn the type of junk email each individual user receives and prevent that reaching his or her inbox. AISEC was shown to be very effective and has since been developed into a user application and is just undergoing readiness for deployment as free software.

Andrew's current investigations are concerned with the mining of interesting information from websites. This is the discovery of relevant pages (like traditional search engines) where these pages must also offer surprising or novel information. He employs an AIS to intelligently follow links to find pages on the assumption that good pages may link to other good pages, and assess a measure of "interestingness" for each one. He adopts the metaphor of interesting webpages to be pathogens and the internet as tissue. His system then allows immune cells into that tissue to find the pathogens (interesting web pages). The immune cells make decisions about where to go to next by choosing hyperlinks on pages based on their affinity (similarity) with the text surrounding each hyperlink. The cells may clone based on how interesting the page is likely to be and may mutate to absorb features of that interesting page. Figure 1, shows the example output from the system.

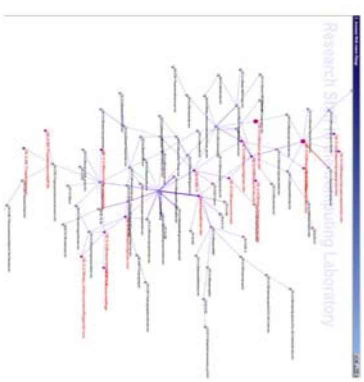

Figure 1 – Output from the Immune Web Miner

C. Immune Memory and Learning

How the immune system learns about and remembers invading pathogens is of great interest. Researchers at Kent have developed a number of immune inspired algorithms, both for supervised and unsupervised machine learning, that capitalise on the memory cells in the immune system.

Andrew Watkins, a PhD student in the group, developed the Artificial Immune Recognition System (AIRS) algorithm, one of the first immune-inspired supervised learning algorithms. AIRS is based on the clonal selection principle, which describes how invading pathogens are defeated by the cloning and mutation of new antibodies. AIRS evolves a set of memory detectors capable of classifying unseen items, and is a supervised learning system. AIRS has recently been extended to a parallel and distributed learning system.

Among the oft-cited reasons for exploring mammalian immune systems as a source of inspiration for computational problem solving include the observations that the immune system is inherently parallel and distributed, with many diverse components working simultaneously and in cooperation to provide all of the services that the immune system provides. Very little has been done in the realm of parallel AIS--that is, applying methods to parallelize existing AIS algorithms in the hopes of efficiency (or other) gains. Two new versions of AIRS have been created, one parallel and the other distributed. Both maintain the accuracy observed in the serial version, but exhibit a significant reduction in computation time.

One theory regarding memory in immunology is known as the immune network theory. Here, B-cells interact with each other to form a meta-stable memory structure though complex interactions of stimulation and suppression. Inspired by this idea, in collaboration with Dr. Nick Ryan of the Computing Laboratory, PhD student Philip Mohr is exploiting the meta-stable properties of immune networks to create a memory structure for use in context aware systems. Philip is developing a system that will identify common behaviors of users based on contextual information such as time, location, day of the month etc. The immune network approach allows for a drastic reduction in the amount of data storage required, making it very attractive for eventual deployment on a hand-held device.

D. Theoretical Investigations

In addition to developing novel solutions to problems, it is essential to have some theoretical understanding of the algorithms. Working with Dr. Andrew Hone of the Institute of Mathematics, Statistics and Actuarial Science at Kent, Dr. Timmis and Dr. Hone are working towards developing a theoretical foundation for AIS based on non-linear dynamics. It is hoped that by employing mathematical techniques widely used for the study of biological systems, it will be possible to analyse the dynamics of AIS algorithms which will give insight into their performance and ultimate usefulness.

E. Integration of Immune, Neural and Endocrine Systems

Finally, in collaboration with Dr. Mark Neal from the University of Wales, Aberystwyth the group is examining the interactions between the immune, neural and endocrine systems and how they lead to homeostasis within an organism. This ability to achieve some kind of steady internal state is both impressive and very useful when one considers the demands of long term autonomy in robotic systems that operate in dynamic environments. Preliminary work has been undertaken to examine the regulatory role of the endocrine system on neural systems for robotic control to enable effective operation in a given domain despite high perturbations in the input space. Work is now progressing on integrating an immune system component to the robot controller to regulate growth within the system.

III. Summary

There is not enough space to explore all the exciting research currently on-going in the University of Kent, but hopefully this has given an insight into some of the activities. There is a great deal of interesting work to be done, and we have only just scratched the surface.

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