INTRODUCTION TO IIDLE

The Immunological Inspired Distributed Learning Environment

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Abstract
The mammalian acquired immune system is a robust and powerful information processing system that demonstrates features such as decentralised control, parallel processing, adaptation, and learning by experience. Artificial immune systems (AIS) are machine-learning algorithms that are imbued with some of the principles, and attempt to take advantage of some benefits of natural immune systems for use in tackling difficult problem domains. The clonal selection principle (or clonal expansion principle) is a theory used to describe the basic properties of the acquired immune system. It is the idea that only those cells that are activated by external stimuli proliferate and differentiate (or are selected), and those that are not activated are selected against. The Immunological Inspired Distributed Learning Environment (IIDLE) is an artificial immune system technique that is inspired both by the clonal selection theory for learning in the acquired immune system, as well as the spatially distributed and circulatory nature of the system. An introductory overview of the IIDLE is provided, highlighting both the inspiration and conceptualisation of the system, as well as speculating as to the expected benefits and applicability of the novel technique.

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1 Introduction

The natural immune system is a complex and interesting collection of specialised organs and processes that provides a defence for an organism against a broad range of external influences. This fascinating biological system has spawned a field of research interested in exploiting the exhibited behaviours, underlying architectural, and process characteristics in computation information systems. This emerging field of study referred to as Artificial Immune Systems (AIS) is intent on building models, algorithms software and hardware systems inspired by immunological function. In this work, a novel learning information system called the Immunological Inspired Distributed Learning Environment (IIDLE) is presented. IIDLE exploits learning and memory properties of the immune system as well as the architectural characterise upon which the adaptive immune system relies.

In Section 1, an overview of the mammalian immune system is provided, highlighting those features and behaviours of interest to constructing an inspired learning system (IIDLE). This is followed in Section 2 by an equally high-level overview of the clonal selection principle that has been accepted as being the most plausible explanation for the learning, memory, and adaptive behaviours of the acquired immune system. Both of these reviews of biological function were based upon de Castro and Timmis' [1] seminal work in the field of artificial immune systems, which is recommend reading for a more in-depth discussion of the topic.

Section 3 provides a conceptualisation of the acquired immune system. This abstraction highlights the spatially distributed nature and the discrete components that make up the active system. Also highlighted is the local (decentralised) nature of mechanisms and processes in the system. Section 4 introduces IIDLE. The introduction begins by identifying and discussing the five desirable properties of the biological immune system that inspired the systems development. This is followed by the identification of five architectural and behavioural processes in the natural system that is fundamental to producing the previously identified desirable behaviours. These architectural descriptions and processes provide the fundamental structure for implement the IIDLE platform.

A specification of IIDLE is provided in Section 5 that is not machine or language dependent and provides an interpretation of IIDLE's design goals detailed enough for constructing a software system in a digital computer. The IIDLE data structure is defined, which consists of localities, tails, and individual units that contain the adaptations or learned knowledge in the system. Further, the three primary localised processes are discussed, specifically movement of units, decay of units and the expansion of units, named after the inspired clonal expansion principle. Finally, Section 6 speculates as to the benefits and suitable applications for IIDLE based upon the system specification and design goals. The main areas of suitability are identified as dynamic problem domains, domains with multiple constraints and finally domains that required robustness of spatially distributed adaptation.

2 Introduction to the Immune System

The immune system is a complex biological system that has evolved to protect our bodies against the constant attack from external microorganisms. It plays a major role in the survival of an organism and therefore it must operate somewhat effectively and efficiently to specifically recognise and selectively eliminate foreign invaders in a host. The system is made up of many distinct components and processes. Recognition and elimination of external microorganisms is referred to as an immune response, and a host that does not succumb to a disease when infected is considered immune. Immune cells specialised for detecting foreign material circulate the body in what can be referred to as immuno-surveillance. Upon detecting a potentially harmful foreign molecule (pathogen), the system extracts and stores useful information from the encounter to better detect and defend against the pathogen in future encounters.

In this work we are concerned with the more evolved immune system found in vertebrates (organisms with a backbone and spinal column), specifically the immune system found in mammals such as mice and humans. There are two principle-complementing components of the mammalian immune system; they are the innate and adaptive immune systems. The innate immune system is the ingrained immunity in a host organism that is developed over evolutionary time. It is able to combat a wide variety of bacteria without any previous exposure over the host's lifetime. It consists of natural barriers to microorganisms entering the host's body and provides the first line of defence. The adaptive immune system is also referred to as the acquired immune system because the host organism acquires or learns a defence against pathogens it is exposed to over the course of its lifetime (not evolutionary time as in the innate immune system). It is called the specific immune response because its principle task is the production of antibody molecules that bind to and aid in neutralising specific encountered pathogenic material. Cells in the acquired immune system called lymphocytes (white blood cells) are capable of remembering infectious stimuli, providing an adaptive ability to better combat or prevent the reinfection by the same pathogen in the future.

A feature of the innate immune system called the complement system is responsible for eliminating foreign cells and microbial infections. An interesting property of this system is that it aids in increasing the blood flow to an infected region, and increases the permeability between tissue and blood (a cause for inflammation and reddening of the skin). These changes allow a larger number of immune cells to enter and be recruited at the site of infection. In essence, in response to a stimulus, the system attracts or facilitates the allocation of additional resources to combat an infection.

Fundamentally, the acquired immune system is concerned with the problem of maintaining a population of recognition cells that must effectively and efficiently handle the problem of differentiating between self and nonself (foreign) molecules. Detecting self as nonself leads to autoimmune disease (destruction of healthy tissue) and not detecting foreign molecules quickly leads to infection and ultimately death of the host. Thus, the problem of self-nonself differentiation is a difficult task, critical to the survival of the host organism.

3 The Clonal Selection Principle

Lymphocyte cells are responsible for the recognition and elimination of external agents in the acquired immune system. They are not activated until exposed to an external stimulus. A Lymphocyte cell (for example a B-cell or T-cell) has receptors on its surface that have a single or mono-specificity. This means that the receptors are capable of detecting, and thus the cell is capable of binding to pathogens with a single and specific structural feature. Cell receptors are defined by mechanisms of its gene arrangement during its development. These sequences are recombined to provide the initial or base heterogeneous repertoire of detector cells in the host. The gene sequences facilitate millions of different receptor configurations, and each lymphocyte cell has a unique receptor configuration or specificity to a specific structure feature. These cells circulate through the host's body seeking and surveying for foreign molecules.

Clonal selection principle is a theory that is core to the understanding of the adaptive immune system. It provides an explanation and way of thinking about the learning and memory properties of the adaptive immune system. The theory was formalised in 1959 by McFarlane and Burnet and is accepted as the most plausible explanation for the behaviour of the system, although alternative theories exist such as the controversial immune network theory (also referred to as the idotopic network theory). When a B-lymphocyte cell comes into physical contact with an antigen molecule (and has a sufficient affinity match between the structure of the molecule and the cells own receptors) it proliferates (divides) into a clone (group) of cells. These cells then differentiate into cells with similar properties (their specificity to the activating antigen), though with different functions. Some become plasma cells that do not divide themselves, instead focus on releasing many antibodies that are capable of binding to, and neutralising pathogens with the same specificity as their parent cell. Other cells become long-lived memory cells that retain the specificity of the original parent B-cell and remain within the system for an extended period.

This process of proliferation and differentiation is referred to as clonal expansion, as the clone (group of) lymphocyte cells capable of detecting a specific molecule structure feature is increased. As mentioned, when the B-cells are prepared initially, they are done so using a recombination process of their genes to seed the base population of cells with a useful level of diversity. During the B-cell proliferation process stimulated by an external agent, the clone of produced cells are modified using what is referred to as hyper-mutation. This process is performed in an attempt to vary and potentially increase the specificity (affinity of the binding) of the antibodies released to the antigen that triggered their release. In this manner, it is considered that external antigens positively select lymphocyte cells in a way that is commonly equated to Darwin's theory of natural selection. Cells that are not selected are not provided an opportunity to proliferate, and eventually die and are removed from the system (atrophy). It is interesting to note that a pathogen may enter the host at any point, and that only those lymphocyte cells that come into physical contact with the foreign molecule are capable of being selected (made use of). This final critical point highlights the diversity and redundancy of the system.

Antigen recognition is not sufficient; the immune system must ensure there are enough resources for future unknown antigenic exposures. The system must carefully allocate and manage its resources such as the size of the clone for a specific antigen relative to the total antibody repertoire. Learning (increasing speed and effectiveness of response) can be achieved in the system in a number of ways such as increasing the size of the clone and adjusting the affinity of the clone. As discussed, each lymphocyte cell is mono-specific (capable of detecting a single structural feature), though this feature may occur on many different molecules. This cross-reactivity or ability to detect a range of different molecules with a common feature is a form of generalisation that permits the pool or repertoire of lymphocytes to be smaller than the set of possible pathogens (more efficient). This behaviour is also the basis for why vaccination works. The intent of learning is to bias the antibody repertoire towards a population that better reflects the actual antigenic environment in which the host lives (specialised to host living conditions). The total number of lymphocytes is regulated. The size of each clone changes over time based on the frequency of exposure and to learn new antigens others must be forgotten to some degree. Intrinsically, the adaptation and learning behaviour in the system in response to external stimuli can be categorised as a reinforcement learning system.

4 Inspiration and Conceptualisation

The mammalian immune system is an intriguing natural defence system that has been shown to be capable of learning, memory, and adaptation. Conceptually the active acquired immune system can be taken as a spatially distributed yet circulating (immuno-surveillance) and heterogeneous population of specialised discrete units that provide a homogeneous defence against external pathogenic material. The units themselves are atomic (operation applied entirely or not at all) and immutable (specificity is fixed for the units lifetime), though once activated or triggered by an external stimulus are capable of proliferating and differentiating. Not only does the distributed learning system respond to a random (spatially and temporally) external stimulus, as shown in the case of the complement system in the innate immune system, it is capable of manipulating the local physiology to facilitate the allocation of more resources to the site of infection.

This manner of learning can be considered decentralised (no global controlling process); given an external pathogen can arrive at any spatially distributed location in the system. Further, the system is robust both in its ability to learn to defend itself and the host organism over time, and in that it is not dependent upon any single or for that matter local group of units for the effectiveness of the system (quantities of blood can be drawn or lost). In fact, a limb can be removed from the host, and although the host will be greatly affected, the loss of immune system cells will not devastate the defence system.

In this work, we are not specifically interested in the anomaly detection or self / nonself recognition properties of the acquired immune system. As stated, we are interested in the learning, memory, and adaptation properties of the system, as well as a conceptualisation of the architecture and processes that facilitate the mentioned desirable information processing properties. The next section provides an overview of the immunological inspired distributed learning environment (IIDLE), which is shown to be designed with the architectural principles of the acquired immune system, and be imbued with simplified versions of some of the immunological processes that are expected to lead to a robust, decentralised, and effective learning system.

5 An Immunological Inspired Distributed Learning Environment

The proposed immunological inspired distributed learning environment (henceforth referred to as IIDLE) is an artificial immune system inspired by the mammalian immune system, specifically characteristics of the acquired immune system. It is a system or environment more than an algorithmic procedure as its definition describes both architecture (data structure) requirements as well as process specifications. It is a system specification that once implemented facilitates a specific application, commonly referred to as a meta-heuristic.

The intent behind the development of IIDLE is to propose a learning algorithm, (a system capable of adaptation and memory of past adaptations) that is capable of exhibiting some of the benefits observed in the acquired immune system when considered a learning algorithm. The five primary desirable system features identified from the acquired immune system to be imbued into the proposed information processing learning system are as follows:

1. **Context specific learning:** from a random starting positing (pseudo-randomly prepared base repertoire of lymphocytes) the system is capable of being activated by any antigen it is exposed to (with some level of specificity) and learn a defence in response to the specific environment, which the host organism inhabits (perhaps a general learning or search capability).

2. **Decentralised system control:** global learning occurs through local interactions, thus a master or global management process is not required. This is a property useful in distributed learning systems, where the geographically local portion of the system in relation to external data-feeds can respond and learn from the stimulus.

3. **Self-regulation of resources:** allocation of additional resources spatially and temporally when required, and the scaling back of resources at times of inactivity. Whilst being decentralised, the local maintenance processes of the system are able to usefully and effectively redistribute resources in response to the systems state.

4. **Triggered adaptation:** learning and system modification that occurs when external information is made available, meaning that the rate of stimulation (and thus the limited information extracted and captured) is defined by the environment in which the system is situated (ad hoc or sporadic as in many types of dynamical problem domains).

5. **Robustness and resilience of memory (knowledge):** a lack of dependence or reliance on discrete system components. System components can be removed, killed or fail (and perhaps added) whilst the system is online, with little to no detriment to the efficacy of the system.

The adaptive immune system was selected as an inspirational metaphor because of the above five primary desirable system characteristics, and because of the success observed in literature using the metaphor for machine learning applications. Being an inspired system, the design of IIDLE attempts to capture the desirable features of the adaptive immune system through using inspired architectural properties and processes (abstractions and or simplifications). The following lists those five primary structural characteristics and system processes that have been identified as imbuing the natural system with the desirable characteristics, and thus the characteristic that are the basis for the proposal of IIDLE:

1. **Spatially distributed population of discrete units:** The adaptive system is composed of discrete, immutable specialised units that are spread across the circulatory system of the host organism. The distributed nature exploits or facilitates the decentralised nature of the learning and regulatory processes.

2. **Heterogeneous population with homogeneous global affect:** Each discrete unit is unique in that its specificity to a specific molecular attribute is slightly different to all other units in the system (for the most part). Further, the units are mixed up and dispersed throughout the circulatory system, providing increased global effect through mobile concentrations (clone size).

3. **Continuous motion or circulation of discrete units:** The units are in constant motion throughout the circulatory system providing a surveillance (seeking activation) whilst at the same time facilitating the redundancy of the units in the system.

4. **Positive selection and proliferation of useful discrete units:** Those units that chance exposure to external stimulation proliferate and live on through their progeny. This clonal expansion process is core to the local adaptive nature of the entire learning system. Through differentiation the system diversifies the clone both increasing concentration (more rapid response), and through hyper-mutation attempts to increase the affinity of the bond on activation (a more effective response). These processes are inspired by the clonal selection principle.

5. **Decay of discrete units:** Each discrete unit in the system is individually redundant or unnecessary (expendable), though the emergent property of all the units in the system represents the global "knowledge" learned through exposure experience. All units in the system age and eventually die, thus those that are proven useful through chance encounters with pathogens live on through the results of local clonal expansion processes.

The next section provides an overview of how the identified architectural characteristics and processes can be interpreted and implemented as an immunological inspired distributed learning environment in software on a digital computer.

6 IIDLE Implementation Specification

Although not language or machine specific, this specification for IIDLE provides an interpretation in terms of data structures, connectivity and process configurations for the identified architecture, processes, and desirable characteristics of the acquired immune system that inspired IIDLE. The framework is data-structure centric, in that the discrete units represent the knowledge possessed by the system, as well as the substrate for which the learning and maintenance process are executed. From a systems perspective there is a weak coupling between the data structures and processes, and a weak cohesion between processes that facilitates high modularity of design and flexibility of application. As such, the data structure will be described first, followed by the processes that operate upon it. This conceptualisation permits alternative, perhaps more specialised data structure configurations to be defined, as well as different or more problem specific processes, or both.

6.1 Architecture

The continuous circulatory system that provides the transport medium for the discrete units is discreterised (made discrete) to a number of **localities** chained together. Each locality is connected to one or more local localities to form a neighbourhood. A locality provides both a scope at which to apply local processes such as movement, decay, and expansion in response to external stimulation, as well as a transient storage location for discrete units. A locality can be conceptualised as a physical positioning of a part of the system that can support a population structure whose contents are transient and temporary. The user must select the number of localities to include in the system and the manner in which those localities are connected. A simple ring network topology is suggested for simplicity and its relationship to the inspirational metaphor, although the investigation of the effects of various connectivity configurations in IIDLE (such as small world and peer-to-peer) remains an area for further research.

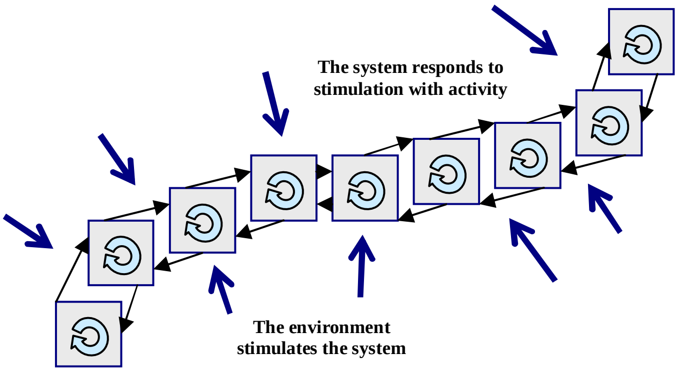

Figure 1 - A conceptualisation of IIDLE showing locality connectivity, external stimulation, and internal activation

A locality supports a population structure called a **tail** that stores discrete units at any given time. The reason it has been referred to as a tail is simply from the aesthetics when the structure is drawn, differentiating it from both the locality to which it is associated and the units, which it contains. The reason for the differentiation is both for conceptual modularity (the specific data structure can be interchanged depending on the problem domain), and for additional implementation reasons such as the ability to persist the structure during a simulation or use an offsite or large-scale storage medium. The locality and the tail together can be considered not dissimilar to a more conventional population in the context of evolutionary algorithms and particle swarm optimisation. In this case, the locality is used to refer to the physical position or situation and interface to the environment of a discrete element of the circulatory system, and the tail is the actual discrete segment of the simulated circulatory system.

A tail contains a number (or zero) **units** at any given time during the simulation. Each unit is a discrete piece of information, meaningful in the context of the specific problem domain. For example, a unit may represent a candidate solution in the case of search and optimisation or it may be representative of a part of a candidate solution in the case of classification, a preference system, or function approximation. Units represent both the knowledge learned and retained by the system from its exposure to external stimuli, as well as the substrate on which adaptation occurs.

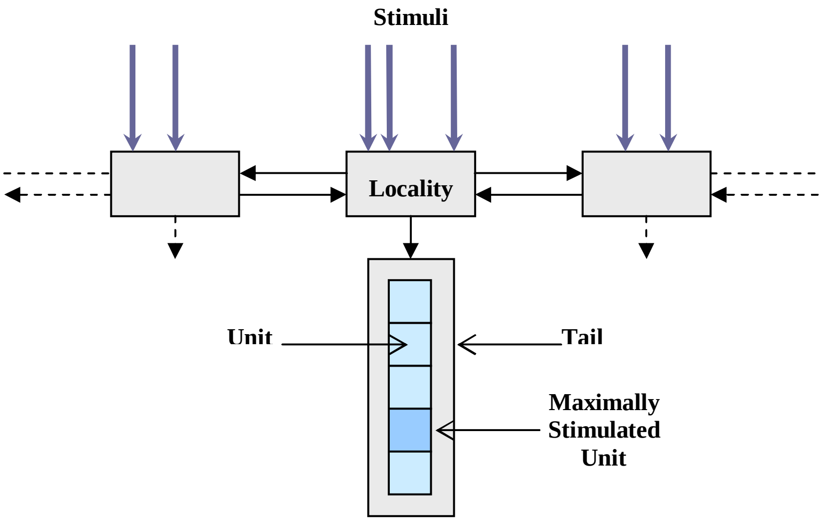

Figure 2 - Overview of the IIDLE architecture showing localities, tails, and units

6.2 Processes

As has been hinted at, the system is simulated in discrete and consistent time steps. Each process can be conceptualised as its own thread of execution that operates upon the data structure at each time unit. It is also reasonable to consider a sequential application (for single CPU machines or non-multithreaded implementation) of the described processes as the effect of their ordering (given consistent frequencies and magnitudes of execution), is expected to be of minimal impact to the performance of the system. Interestingly, each process can be configured for a variable scope of execution on the underlying data structure – a benefit of the modularity and separation of architecture and processes. In conjunction with the expected per-locality process configuration, localities can be grouped by a domain specific feature or partitioned by geography and the processes configured to operate at these high-level scopes. These are implementation-specific and configuration dependent properties that are worthy of further investigation.

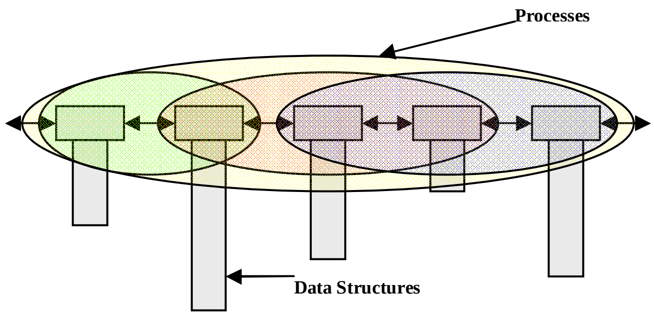

Figure 3 - An illustration of the weak coupling of data structure and processes as well as the variable scoping of processes on data structures

Movement is the process of removing units from one locality to one of the neighbouring localities. This is a simplification of the circulatory system, though in this simplification, the selection of the unit to move is random, and the direction it is moved is also random (unlike the circulatory system that is unidirectional). An alternative though not adopted movement procedure would be to have a consistent movement direction, thus providing a closer match to the inspired biological system. This configuration was not chosen, as although it provided consistent and easily calculable information dispersal times given an external stimulation, the configuration was less amenable to ad-hoc and irregular locality connections, locality failures and locality additions.

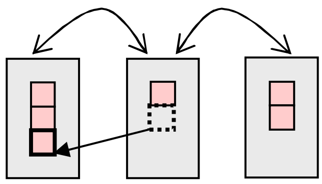

Figure 4 - A simple illustration of the movement of units from one locality to a locally connected neighbour locality (really one tail to another, where localities provide the connectivity and interface)

Each unit in the system is independently redundant to the efficacy of the system. The decay process (also referred to as the resource regulation process) is responsible for decrementing the energy scoring associated with each discrete unit. This energy scoring is initialised to a constant value upon the creation of the unit and is different from any fitness or quality measures that may be associated with the unit. Decay can be implemented either as a constant decrement to a units energy each execution of the process or as an explicit regulatory process that seeks to maintain an equilibrium in regard to the total amount of energy in the system (or the scope over which the process is applied).

The first approach is referred to as *conformer homeostasis* that (although a simplification) is a closer fit to the processes within the inspired metaphor that regulates the resource allocation of the immune response (lymphocyte population). The system uses fewer resources in times of inactivity, and increases for resources at times of greater activity. Further, the self-regulating processes are decentralised, permitting non-uniform allocation of resources across localities in response to the environmental stimulation. Such a configuration is suited to dynamic problem domains that are required to ramp-up and ramp-down in response to information loads both temporally and spatially. The second approach is referred to as *regulator homeostasis* that attempts to maintain a variable (in this case locality energy and or system energy) at a mean desirable value. The value is permitted to fluctuate somewhat in response to the environment, though equilibrium is always sought by the regulating process. Such a configuration is suited to domains in which there is complete control over the frequency, magnitude, and location of external feedback and thus fixed resources can be allocated to the problem such as static search and optimisation domains.

The final process is responsible for the adaptation and ultimately the learning within the system. Broadly, this process is referred to as expansion, after its inspiration from the clonal expansion principle (a.k.a. the clonal selection principle). It can be conceptualised as three sub-process as follows; *stimulation*, *selection* and *proliferation*.

Stimulation is conceptually an external input that triggers the adaptation (learning) process. Like the other processes, the locality provides the outward interface to the process, or in this case the stimulation from the environment in which the system is situated. In the domain of novelty detection or classification, input may be a collection of input patterns to which the system must respond. In the case of a search or optimisation problem, stimulation may be to provide access to an objective function of some kind. This demonstrates that the conceptual stimulation of a locality may be the *provision of computation time*, *provision of a memory resource* or *access to a limited resource*, which the system is expected to make use of and respond to. Stimulation can be sporadic as in the temporal and spatial random arrival of pathogens in the inspirational metaphor, or uniform and consistent as required by the application problem domain.

The external stimulation of a locality results in an internal proliferation and differentiation process within the tail data structure of the locality. This starts with the application of a selection algorithm that determines the unit(s) to participate in the expansion. The selected units are expected to be those units within the locality at the time of stimulation that are demonstrated to be the most efficacious or useful in the context of the problem domain. The proliferation and differentiation process uses the selected units in an algorithm that produces a configured number of progeny units that are in someway similar to the parental units. In this way, a clonal selection-like algorithm is used to re-sample the problem space in a directed manner not dissimilar from other Monte Carlo based search strategies (at least within the context of a single locality).

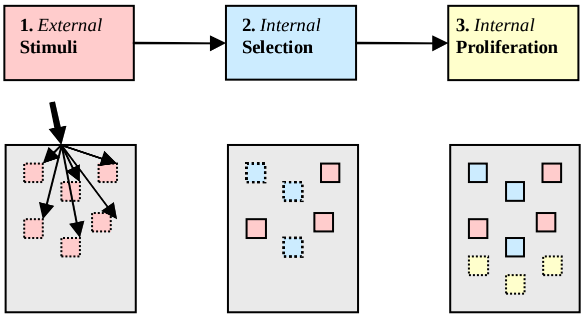

Figure 5 - Overview of the expansion process showing external stimulation, internal selection and internal proliferation and differentiation

7 Benefits and Applicability of IIDLE

The description of the IIDLE specification shows that the framework is problem non-specific and somewhat flexible concerning implementation and configuration. In this regard, the system can be considered a meta-heuristic technique in that it is a higher-level approach for combining and exploiting lower level problem-specific heuristics. The benefits of using IIDLE as well as those applications for which IIDLE is best suited are unknown and remain an area for further investigation. Using the description of the desirable features that inspired the development of IIDLE as well as the architectural characteristics and processes used within the system, it is not unreasonable to conjecture as to the possible benefits and application to which it may be worth investigating in the context of IIDLE. The following speculates at five features and problem domains to which the system is expected to suit:

1. **Parallel implementations and distributed problems**: The fact that the processes that regulate resources and adaptation within the system are decentralised and the fact that the population structure is modular and distributed imply that the system is amenable to both distributed (parallel

implementation across a computer network) implementations as well as those problem domains which require adaptations at spatially distributed locations whilst sharing information between locations.

2. **Dynamic problems and variable load**: A central theme to the design of the system is that the environment triggers the system with a stimulus to which the system must respond by extracting knowledge from the encounter. Like the problem faced by the natural immune system, IIDLE is amenable to dynamic adaptation problem domains, both in regard to the nature of stimulation the system receives as well as the load (frequency and magnitude) of information the system receives across its spatially distributed locality interfaces with the environment.

3. **Collaboration, reconfiguration, and interactive search**: Similar to the systems amenability to dynamic problem domains, it is also amenable to collaborative learning problems such as recommender or preference systems. Further, given the robustness and speculated insensitivity to configuration parameters the system is amenable to dynamic reconfiguration, allocation of additional or less resources in real-time as well as various forms of human-interactive search strategies.

4. **Multiple objective and multiple constraints**: External stimulation was purposefully described as a vague concept to facilitate flexibility in terms of applicable problem domains. One way in which this flexibility of specification can be exploited is by addressing problem domains that require multiple objectives or require solutions that must fulfil multiple constraints. Such problem domains could be addressed by partitioning localities by constraints and or objectives. Solutions capable of "surviving" under the pressure of each type of stimulation would thrive in local regions of the structure, whilst information sharing facilitated by the movement process promotes the global search requirements of this problem type.

5. **Embedding of common search strategies**: The proliferation stage in IIDLE's expansion process was described simply, akin to a search process such as directed random search where progeny samples are generated within a local region of the parent sample. As was hinted at in this specification, alternative search strategies can be embedded in IIDLE to perform this task, providing a technique specific bias in the manner in which progeny units (samples) are created. Alternative proliferation strategies include evolutionary algorithms (eg. Genetic algorithm), ant colony optimisation (eg. Ant systems with discrete history) and particle swarm optimisation.

8 Conclusions and Further Work

A lot of ground has been covered in this introduction to the proposed immunological inspired distributed learning environment. After a brief overview to the mammalian immune system and the clonal selection principle, a conceptualisation of the immune system was proposed and the desirable characteristics of that conceptualisation were identified. The underlying nuts and bolts, fundamental architecture and simplified processes that were selected as to facilitating the desirable characteristics of the adaptive immune system were listed as design goals for an inspired learning environment. IIDLE was presented as a platform and general specification for learning in a manner resembling clonal expansion in an architecture that resembles a discreterised circulatory system. Finally, some benefits and potential applications for the proposed learning environment were proposed.

Some preliminary experiments have been performed with an implementation of the framework that is discussed in an upcoming technical report. A number of easily visualised two-dimensional function optimisation problem domains were tested with success. Both dynamic versions and multiple constraint satisfaction variations of the functions were shown to be addressed efficiently and effectively by the system. A number of travelling salesman problems (TSP) (well known combinatorial optimisation problem) were also tested in the system with success. A partitioned, multiple constraint approach to the problem was tested using tour length, number of nearest neighbour connections and number of intersections. In addition, a human interactive version of the problem was tried where the human operator commented on the "*messiness*" of the presented TSP solutions. Both sets of preliminary works provided useful and interesting results.

Going forward, more rigorous experiments are needed for IIDLE to both gain quantitative results on specific common static and dynamic problem domains to assess its effectiveness as a tool, as well as qualitative results on the problem domains to aid in future configuration on unseen application domains. This is an urgent area of work for IIDLE such that a rigorous preliminary understanding of what IIDLE is and how to use it is attained before progressing further with the work.

The natural immune system is an exciting base metaphor for computation and learning systems given its variety of desirable information processing features and architectural traits. IIDLE is a newly proposed and untested artificial immune system that superficially resembles bits and pieces of existing search techniques both in the field of AIS and beyond. The relations of IIDLE to related literature is an area of work that needs elucidation to appreciate the novelty that the framework presents.

9 Bibliography

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