Towards Unification...

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***Abstract*-This work provides some work towards the unification of the work completed to date as an immunological-inspired cognitive paradigm.**

Keywords-Clonal Selection Theory, Acquired Immune System, Artificial Immune System, Cognitive Immune Paradigm

I. THE MODELS

To date, much effort has been directed towards proposing models and architectures to house the clonal selection theory [1,2,6], and more recently, steps towards the realization of these models [4,5], specifically in the context of a consolidated pathogenic exposure paradigm [3].

The out come of this work may be summarised as follows:

Architectures: Three distinct architectures to house clonal selection models, each with their own specific concerns (single repertoire, multiple repertoires, and multiple systems)

Components: Many components and component types have been defined. In addition, the tiered abstraction of architectures allows subsumed levels to be used as components at the following level (cell types, tissue types, model types)

Processes: Many different processes at each of the three levels of abstraction of the system, each with their own concerns (adaptation, homeostasis, movement, evolution, and immunization sharing)

Environments: An environmental paradigm was devised which facilitates stimulus-response adaptation of a situated system (exposure, multiple exposures, and multiple pathogens)

Some concerns of the above models that have not yet been reconciled are as follows: (1) a well-defined germinal centre adaptation algorithm, (2) reconciled polyclonal activation and response (an aspect of the cognitive paradigm), (3) a reconciled homeostatic algorithm, (4) a reconciled memory-forming algorithm

Some additional concerns which have not yet been integrated into this emerging broader system-environment paradigm are as follows: (1) two-phase activation of B and T lymphocytes, (2) reconciled immune network regulation algorithm.

II. CLONAL SELECTION IS...

A parallel thrust of work has considered clonal selection from a number of different perspectives, including biological, theoretical, and computational learning. Clonal selection is:

A. *Biological Perspective*

Immunological Theory: It is a theory that explains the diversity of antibodies via antigenic selection of lymphocyte receptors, which takes into consideration the potential for the production of antibodies that may attack self-tissues.

Antiquated Immunological Theory: It is a theory of immunology proposed before the era of molecular science and genetics. It fosters a perspective of discriminated self and nonself, which does not match evidence regarding autoimmunity. It has been augmented with an idiotypic network theory and superseded by danger theory and a cognitive theory of immunology.

Clonal Activation Process: It describes a process whereby a relatively high-affinity lymphocyte receptor binds with an antigen, resulting in rounds of cell proliferation, differentiation, mutation, and additional selection. A specialised version of the process applies to both T-lymphocytes and B-lymphocytes.

B. *Machine Learning Perspective*

Adaptive Plan: It is a general methodology for a stimulus-response form adaptation from pseudo-random initial conditions, where an environment triggers learning and information is managed through altered receptor (genetic) densities.

Learning Algorithm: It is a procedure for population-based learning through the mechanisms of selection, proliferation, and genetic operators for instantiation and mutation.

Cognitive Paradigm: It is an integral component in a broader cognitive paradigm when broader notions such as environment, architecture, and regulatory processes of acquired immunity are taken into consideration. It describes a machine-learning paradigm for investigating cognition and adaptation.

C. *Others*

Clonal selection also bares similarity to a number of existent machine learning and artificial intelligence

approaches, not limited to the following list:

Approach	Similarity to clonal selection
Lazy Learning	Knowledge is stored in exemplars, and adaptation (model forming) is haphazard at the time it is required (just-in-time or triggered learning)
Competitive Learning	Winner-takes-all principle for activation and response, with self-organizing properties
Neural Networks	A stimulus-response approach to learning with a sub-symbolic representation
Swarm Intelligence	Emergent computation from the activity of small unwitting components
Hill-Climbing	Rounds of selection and hypermutation provide a directed hill-climbing effect
Evolutionary Computation	The principle operators are a population, selection, and genetic operators
Classifier Systems	A number of internal learning processes for dynamic learning in contending with perpetual novelty.
Reinforcement Learning	An agent learning using a trial-and-error approach in the face of minimal and delayed feedback

Table 1 - Similarity to artificial intelligence approaches

III. A Subsumed Architecture

The three-tiered abstraction described in modelling the clonal selection facilitates a natural subsumption architecture of layered hierarchical computation.

1) A *cell* in a *repertoire* is exposed to a *pathogen*

2) A *repertoire* in a *system* is exposed to *pathogen*

3) A *system* in a *population* is exposed to *pathogen*

In this architecture, the properties of the pathogenic exposure paradigm apply at all levels. In return, the general principles of the specialized processes and components at each level also apply at all levels.

At the single repertoire level, the unit of adaptation is the cell, with multiple repertoires (a system) the unit of adaptation is a repertoire of cells, and with a population of systems, the unit of adaptation is an entire system. Similarity movement of these units may be employed at all levels such that there is intra-repertoire, intra-system (inter-repertoire), and intra-population (inter-system) movement respectively. The subsumption architecture describes information management (creation, application, modification, sharing, and deletion) at three connected levels of abstraction.

Similarly, the pathogenic environment paradigm applies to all three levels, such that a repertoire, a system, and a population are subjected to exposures, multiple exposures, and multiple pathogens. Each level may has its own concerns, configurations, advantages, and disadvantages when considered in isolation, as has been the focus of the work completed to date. What has not been considered is the behaviour of a vertically integrated system (as opposed to simplified reductions when considering each level independently).

Another observation is that the surrounding modelling levels of abstraction provide perspective on the requirements and concerns for a given level. Exploiting this observation, one may push the abstraction one additional step in each direction, in an attempt to gain further insights on the two bounding ends of the hierarchy.

Genetic Level: At a level below the cellular (single repertoire), model is the genetic-material level. One may consider a genome of genetic material which collectively has meaning, although individually provide components which contribute to this solution. Genes switch on and off, and mutate. This is a component level at which the same general principles of information management apply.

Ecosystem Level: At a level above a population of immune systems are multiple populations of systems, where different populations have different concerns. Thus, we may envisage an ecology of interacting organisms with immune systems, where one level of the ecology may be concerned with the invasion of another level of the ecology, a challenge between immune systems (offensive and defensive).

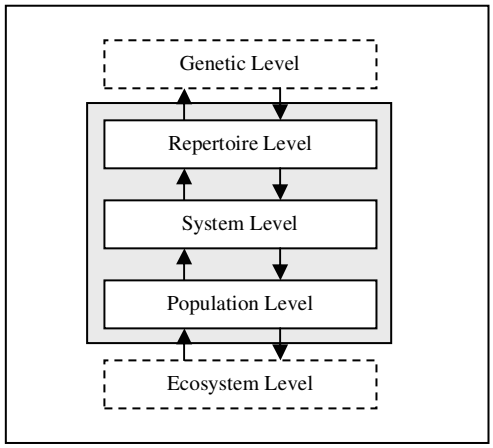

Figure 1 - Depiction of the immunological subsumption architecture

1) A *gene* in a *genome* is exposed to a *pathogen (other genome?)*
2) A *cell* in a *repertoire* is exposed to a *pathogen (other cell?)*
3) A *repertoire* in a *system* is exposed to *pathogen (other repertoire?)*
4) A *system* in a *population* is exposed to *pathogen (other system?)*
5) A *species* in an *ecosystem* exposed to a *pathogen (other species?)*

Figure 2 - Summary of the extended hierarchy

The levels are named after the names of collectives of adaptive units, although the levels could just as easily be named after the units of adaptation at each level (genes, cells, repertoires, systems, and species). It should be pointed out, that through the architecture; genetic operators are the means of adaptation, both somatic (clonal selection theory) and generational (neo-evolutionary theory). A second observation is that the pathogen exposure should match the unit of selection (as highlighted in the parenthesis in Figure 2). This provides a way to assign previously ill-defined constraints such as magnitude, virulence, and regime of a pathogen (in the pathogenic environment paradigm).

Level	Immune System	Pathogen
Genetic	Gene	Gene
Protein/Cellular	Paratope	Epitope
Repertoire	Cell (receptor)	Pathogen (one cell)
System	Tissue (lymphoid)	Pathogen (tissue)
Population	Host (system)	Parasite (organism)
Ecosystem	Species (population)	Species (population)

Table 2 - A tentative mapping of the hierarchy

This mapping between an immune system and a pathogen against the hierarchy further standardises the framework.

The proposed architecture is (should be) implementation neural. Conceptually, one may envisage the architecture as a hierarchy of one-dimensional structures (circular arrays) suitable for implementation and preliminary investigation in software.

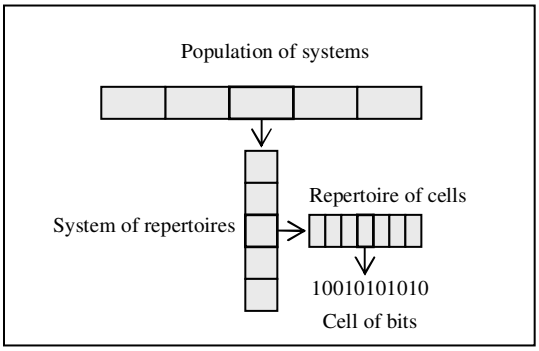

Figure 3 - Depiction of the hierarch architecture as one-dimensional arrays

This simple conception simplifies many of the details of the biological model, whilst facilitating many of the intended process (and hopefully emergent effects) of the system.

Given this architecture, one may investigate one level in and knowingly simplify (constrain) the levels below and above. Alternatively, one may implement a number of levels and investigate the effects of integration. Finally, one may mash-up the hierarchy, selective taking processes, and components from across the vertical arrangement.

IV. A Cognitive Platform

Learning classifier systems are a paradigm for investigating cognition and adaptation in environments with similar characteristics as those to which humans and animals are subjected. As a system, they are a handcrafted computational platform that employs reinforcement-learning algorithms and genetic algorithms to address classes of dynamic-learning problems. The acquired immune system provides a biological-basis for constructing such computational platform with similar goals.

Environment: The pathogenic environment (previously described), is an immunological abstraction which strongly resembles a general definition of a reinforcement learning task. Thus, the strategy employed by the acquired immune system may be phrased as a reinforcement learning approach.

Units of Adaptation: The cells may be considered the discrete units of adaptation (at the repertoire level), thus clonal selection provides a process for creating new classifiers that are variations on relatively high-affinity existent classifiers. The perpetual creation of new cells from the genome also facilitates the systems capability of handling perpetual novelty in the environment. These are two types of genetic operators, very much like the genetic operators used in LCS.

Internal Activity: The system is in a state of continual activity not limited to the turnover of the lymphocyte population (attrition) which manipulates the densities of receptors and the migration of lymphocytes throughout the system, which diffuses the densities of receptors.

Decoupled Condition and Action: The condition and the action may be decoupled in the implementation of both B and T lymphocytes. The B lymphocytes are concerned with antigen in its raw state, breaking it down internally and presenting it on the surface of the cell. The T cells are concerned with the decomposed antigen on the surface of the B cells (antigen presenting cells). A B and T lymphocyte clonal activation does not occur unless an activated B cell in-turn activates a T cell. This provides a two-phase process for adaptation: stimulation, trigger, activation, where competition mediates the systems ability to adapt.

In considering the immune system as a natural model of a LCS-like system provides a motivation for investigating the proposed immunological subsumption architecture. The architecture (or parts there of) naturally facilitates the adaptation of a distributed set of classifiers. It has been demonstrated that the immune system possesses: (1) genetic operators for rule discovery, (2) competition for rule activation, (3) receptor attrition and movement for internal (environment-independent) activity, and (4) receptor densities for credit assignment. Although not a mapping of a classifier system, the biological metaphor does demonstrate many principles of a classifier system, strongly suggesting a direction for further research, and potentially application of the proposed hierarchical architecture.

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