Towards General Information Processing Models of the Acquired Immune System

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***Abstract*-Previous works on the hierarchical acquired immune system framework have remarked at the strong similarity with regard to the information processing properties between the tissue and host algorithms. In particular the distinction between such algorithms may be considered ambiguous, specifically with regard to the minimal variation of algorithms at such scales in the framework. This work addresses this concern and in doing so identifies the potential for more commonality between the scales of the hierarchical framework. In addition to the minimal information processing properties between the tier, the additional commonalities are identified such as the interactions between principle components, and the triggered nature of adaptations. These identified common and abstracted information processing concerns are proposed as the first steps towards devising general (cross-tier) general information processing models inspired by the hierarchical framework.**

Keywords-Acquired Immune System, Framework, Clonal Selection, General Models, Information Processing

I. AMBIGUITY BETWEEN TISSUE AND HOST ALGORITHMS

Issues of ambiguity were raised in the difference between the information processing of the minimal population algorithm and the minimal recirculation algorithm [3]. The raised concerns centred on the similarity between the two algorithms, specifically the fact that both consist of semi-isolated populations of cells subjected to the principles of clonal selection sharing information with each other according to some governing interaction principles. These concerns were further highlighted when a minimal tissue algorithm was proposed in which, like the minimal population algorithm, there are no interactions between the populations of cells [2]. This additional minimal algorithm was also predicted from an 'systems interaction' perspective that divides the algorithms of the hierarchical framework into their innate interactions [1]: (1) algorithms with exogenous interactions with principle components, (2) elaborated algorithms, and (3) algorithms with endogenous interactions between principle components.

***Algorithm Ambiguity**: Tissue-based algorithms and host-based algorithms are primarily concerned with the interactions between populations of cells operating under the principles of clonal selection*

It is useful to first explore the basis of the ambiguity, which is the similarity between the tissue and host classes of algorithm.

***Superficial Similarity**: The commonality between algorithms based on the general principles (abstractions) of their information processing concerns. In the example of the tissue and host case, the superficial similarity is that both classes of algorithms consist of compartmentalised populations of cells operating under clonal selection principles*

There is a superficial similarity between all three tiers of the hierarchical framework. Algorithms at all three levels involve cells subjected to the principles of clonal selection. At the cellular level, the relationship between antigen and the determinants is direct. At the tissue level, the cells are separated into discrete groups (tissues), which mediate the information processing. At the host level, the cells are further separated into larger (or abstract) groups as hosts, which also mediate the information processing at the broader scope. Thus, from the superficial level, the levels of the hierarchical framework partition the cells and constrain the information processing of the cells in different ways.

***Partitions and Constraints**: The different levels of the hierarchical framework partition the cells into groups at different scopes, and constrain the information processing of those partitions at the different scopes*

Thus, an important difference between the algorithms and models at different levels in the hierarchical framework is the change in scale and the organisation and information processing constraints imposed at the changed level of scale. The very nature of the framework, its hierarchical organisation, highlights a related difference, the one-to-many relationship between the tiers. This results in what may be referred to as the maximum-minimum principle in which the maximum in complexity of organisational and information processing constraints at one level, represent the minimum of such constraints at the next level in the hierarchy. The scale of the constraints of one level are subsumed (aggregated and abstracted) by the next level.

***Maximum-Minimum Principle**: The maximum level of organisation and information processing constraints become the minimum of such constraints at the next level in the hierarchy.*

The first example is the relationship between the cellular level and the tissue level. At the cellular level, cells are organised into a flat population and are operated on by clonal selection. Some more complicated information processing principles include different cell casts that mediate behaviour, and inter-population interactions inspired by the network theory. At the tissue level all such complexity is abstracted such that a given population of cells (with whatever organisational and information processing constraints) represents a single unit of adaptation (a tissue) within a population of tissues (a host). The second example is the relationship between the tissue level and the host level. At the tissue level, tissues are organised into a discrete populations of cells and are connected according a directed graph topology. Information processing involves the trafficking of information around the directed graph, first in a semi-organised manner, and later with preferential residence and information requests. At the host level, the complexity of tissue organisations and communication are abstracted such that a given organisation of tissue is but one element (a host) in with in a population of tissue-structures (a population). In addition to demonstrating the subsumptive nature of the maximum-minimal principle, these inter-hierarchy examples highlight the specific differences between the sharing of information (interaction constraints) at the different scales of the hierarchy.

***Minimal Algorithms**: Pathogen provide a unifying influence of a set of otherwise disjoint principle components of the minimal algorithms at all three levels of the hierarchal framework.*

The subsumptive argument of the maximum-minimum principle depends on the difference in organisational and information processing constraints to define the differences between levels, specifically the tissue and host levels. This dependency may be confronted by configuring the algorithms at the two levels in the same manner. One may consider the minimum population algorithm and a minimum tissue algorithm. The minimum tissue algorithm consists of a set of disconnected clonal selection algorithms. The minimum population model consists of a set of disconnected tissue algorithms. The scope of pathogen addressed by each model is different (a habitat of pathogen compared to an environment of habitats respectively). The clear commonality here is the lack of direct interaction between the principle components. The feature that ties the set of components together is the environment in which it is situated, pathogen (on some scale) selecting principle components, which generate a response that likely affects the entire collective. This commonality may be extended further to the minimal clonal selection algorithm that has the same properties.

***General Minimal Algorithm**: A horizontal adoption of the framework (ignoring the information-processing constraints of the hierarchical framework) with regard to each minimal algorithm highlights that all three algorithms are instances of the same general selectionist algorithm*

A horizontal adoption of the hierarchical framework ignores a given level's context (the neighbouring levels in the framework), thus the intrinsic information processing of a given level's principle components are not constrained to the information processing of the previous level in the hierarchy. The abstraction of intrinsic information processing concerns in effect makes them constant between levels. The result is that the minimal algorithms of each level become, in effect, the same algorithm, although addressing pathogen at different scales. This algorithm is a general form the clonal selection principles. The constraints imposed by the abstractions (adaptive models) of each tier define the differences in the interactions between the principle components of the general algorithm. Thus, the interactions (models and algorithms) may be applied to the general algorithm at any scale, not limited to the constraints of the framework, allowing the algorithms and architectures to be integrated.

***Scale Impervious**: Given a horizontal adoption (general clonal selection algorithm), the specialised algorithms and architectures (extensions of the minimal algorithms) of each tier of the hierarchical framework may be implemented at any level of the framework, and integrated into the other algorithms and architectures of that level.*

II. Commonality Across The Hierarchy

The previous section demonstrated the commonality between the minimal algorithms of each tier of the hierarchical framework, such that when a horizontal adoption of each algorithm is taken, one may derive a general minimal (clonal selection) algorithm. This base abstraction opens the door to cross-hierarchy integration of any, and all algorithms and architectures. This section explores the commonality across each tier of the framework, from both a horizontal and vertical perspective, in an effort to providing some tools devising a general model beyond the complexity of a general minimal algorithm.

***Interactions**: The relationships between principle components in a population in which one component selects another and imparts information, both of which are specifically constrained by a given tier on the hierarchy*

Interactions between principle components in algorithms at each level may be reduced to component selection and the imparting of information. For example, in the elaborated clonal selection algorithm, selection may be mediated by information composition or affinity, and imparted information involves conformation of information composition to a variant of the selectee's information composition (replacement by another cells progeny). More elaborate component selection schemes occur in the mediated algorithm and in the intra-repertoire algorithm. The interactions in the tissue algorithm are mediated by the architecture of the population. Tissues are connected according to a directed graph (secondary tissues), with terminally connected tertiary and primary tissues that provide other information process processes. The information imparted between secondary tissues is a sample of information that may or may not be useful to neighbouring tissue or tissues further down the line. Interactions between hosts

in a population, like the interaction between cells in a repertoire are mediated somewhat by the intrinsic properties of each host. Hosts select each other randomly or mediated by proximity in a spatial domain and may transmit direct information about the environment or acquired information about the environment between each other. In the generational algorithms, hosts may interact via reproduction and in cross-generational transmission of acquired information about the environment. Thus, the selection of participating principle components may be controlled by other components and population architecture, and the transmission of information concerns holistic or partial information regarding the environment.

Algorithm	Component Selection	Information Conveyed
Minimal Cell	None	-
Extended Cell	Composition, Usefulness	Variation, holistic
Minimal Tissue	None	-
Extended Cell	Architecture	Acquired information, partial
Minimal Host	None	-
Extended Host	Random, Spatial, Generational	Acquired information, partial

Table 1 - Summary of the component selection and imparted information of the algorithms across the hierarchical framework

The commonality of interaction between the host and tissue levels is clear, they both rely on the population architecture for component selection, and both impart partial information acquired about the environment. This observation may provide a basis for a distributed general model.

Triggered Adaptation*: Information about the environment is revealed to a given system in a piecewise manner, such that the acquisition of information about the environment is triggered by exposures of information by the environment*

The pathogenic environment framework provides a general domain in which a given system is situated and is designed to acquire information about. At the cellular level, the algorithms are passive, awaiting the arrival of pathogenic signals to which to respond. In the case of the mediated algorithm, additional information may be acquired through a feedback mechanism, which may reinforce information. A feedback mechanism for reinforcing information is also employed in the intra-repertoire algorithm where principle components act as pathogen to other principle components. The tissue algorithms are passive models in that they await the arrival of pathogen to which they may respond. A response may or may not be adaptive given the constraints on information processing imposed by different tissue types of the architecture. Independent of exposures to pathogen, the tissues of a host continue to change, adapting to the information provided via continuous inter-tissue interactions. At the host level, like the tissue level, host systems await exposures to pathogen such that they may internally respond. Although, as is the case for the tissue and cellular levels, some host-level algorithms allow hosts to continue their adaptation in the absence of pathogen given inter-host and inter-generational interactions. Further, the host transmission algorithm allows hosts to sample pathogen from the environment and transmit them to other hosts of the system, providing internal source of external stimuli.

Algorithm	Internal-Trigger
Minimal Cell	None
Extended Cell	Inter-cell interactions
Minimal Tissue	None
Extended Cell	Inter-tissue interactions
Minimal Host	None
Extended Host	Inter-host interactions

Table 2 - Summary of the internal triggers for adaptation across the different algorithms in the hierarchical framework

Thus, the algorithms highlight that in addition to all levels being triggered and acquiring information from the environment from pathogenic exposures, that intra-system interactions continually foster the reinforcement and retention of acquired information.

III. DISCUSSION

In addressing the ambiguity of the tissue and host models, a general minimal algorithm was phrased which provides an abstraction and basis for unifying the information processing principles of algorithms across the hierarchical framework.

General Minimal Model*: An algorithm in which a population of principle components independently interact with a pathogenic environment*

In exploring additional commonalities across the framework, general interaction principles were phrased, such that inter-component interactions may be summarised as the (1) selection of the component(s) involved in the interactions and (2) the imparting of information between the selected components. Two important methods of imparting information were identified, (1) the holistic (replacement) method of varied existent information such as used in the elaborated and extended clonal selection algorithms, and (2) the partial (integration) method of acquired existent information as is used in the tissue and host algorithms.

General Holistic Transmission*: The selection and replacement of principle component-wise information. Examples include the replacement of cells in the extended clonal selection algorithms, replacement of tissues (unrealised), and the replacement of hosts (generational algorithm)*

General Partial Transmission*: The selection and integration of sub-principle component-wise information. Examples include the sharing of partial cellular information (unrealised), sharing of partial tissue information (recirculation algorithm), and sharing of partial host information (sharing algorithms)*

Another important commonality identified was the 'triggered adaptation' motif where the adaptation that occurs within each system may have (1) an exogenous (pathogenic environment) or (2) an endogenous (other principle component) causal factor. This identification highlighted the controlled and continual reinforcement nature of the endogenous triggers, and the uncontrolled and disparate nature of the exogenous adaptive triggers. This distinction of interaction types has been identified and discussed in previous work, and provides a useful

observation form the framework [1].

Finally, it is useful at pointing out that although the observations of this work do not clearly outline a general (unifying) information processing model, the components will likely be represented in such a model when it is proposed. Towards this goal, an additional perspective is that of the broader project in which the initial clonal selection and pathogenic environment (system-pathogen) relationship represents the development of the hierarchical framework, the second step, and the reduction to a general model as the final step of the project.

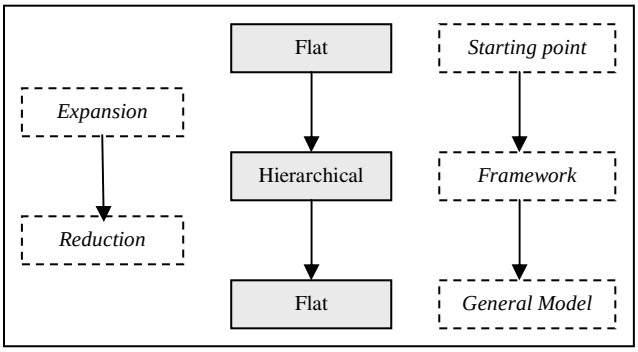

Figure 1 - Perspective of the development of the framework and its proposed subsequent reduction into one or more general models

The initial flat perspective in that of the cellular perspective propagated by the field of acquired immune systems [4], and which provided the starting point for the development of the framework. The hierarchical framework represents an expansion of the flat perspective, firstly of the acquired immune system, resultant models, and inspired algorithms. The expansion provides a richer context to explore and phrase the information processing properties of the biological system and capabilities of such properties imbued into algorithms. Finally, the richer hierarchical framework itself becomes the object of study, with proposed high-level observations and abstractions. Such work naturally leads to the proposal of one or more general, flattened information processing models of the acquired immune system. Such compressed models incorporate some of the richness of the expanded perspective, and provide a scale of comparison with the initial simpler cellular perspective of the field.

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