# A Review of the Immunological Inspired Distributed Learning Environment

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***Abstract*-The IIDLE is a machine-learning framework inspired by the information processing properties of clonal selection in the context of a spatially distributed and recirculation population of lymphocyte in a host organism. The IIDLE may be considered to have been proposed in the context 'systems engineering', with a strong top-down and application centric perspective. This work considers the IIDLE in the context of the previously hierarchical framework of the acquired immune system and related models and algorithms. The main information processing themes of the IIDLE are considered and broader integration of IIDLE and the hierarchal framework is considered.**

***Keywords-Artificial Immune System, IIDLE, Clonal Selection, Distributed, Information Processing, Adaptive, Framework, Algorithm, Integration***

## I. Introduction

A machine learning platform inspired by the adaptive properties of the clonal selection theory, and the spatially distributed properties of the acquired immune system physiology has been proposed called the *Immunological Inspired Distributed Learning Environment* (IIDLE) [7]. The platform was originally proposed [4], with an algorithmic specification [3] and preliminary experimental work [5,6]. Other unpublished work included an incomplete study on 'adaptive' extensions of the principle processes[1], a website with description and software download[2], a research poster, and other notes. Another related work was the then proposed *Discrete History Ant Systems* (DHAS) [1], later released to be an rephrasing of the already published Population ACO framework [16]. The series of work considered many interesting aspects of distributed machine learning and distributed models of the acquired immune system, although such contributions were obfuscated by (1) poor experimental methodology and (2) a top-down 'systems engineering' perspective. The work raised many questions as to the immunological inspiration for distributed information processing. Considering such questions lead to the more recent bottom-up thrust of research, including a series of discrete immune-inspired algorithms [12], and a hierarchical framework [11]. The intent of this work is (1) to review the IIDLE, (2) to disentangle the interesting research contributions of the work, and (3) highlight the questions raised by the work regarding distributed information processing inspired by the acquired immune system. Finally, relationships are drawn between IIDLE and the more recent bottom-up models, algorithms, and hierarchical framework.

Section II provides a review of the IIDLE, highlighting concerns such as motivation for the work, systems architecture, and processes. Section III considers some themes of the IIDLE, specifically from the perspective of the application domains to which the platform was applied, and the general information processing assumptions made. Section IV considers the IIDLE in the context of the hierarchical framework of the acquired immune system and related models and algorithms, relieving that the IIDLE provides a top-down application-centric perspective of realising the distributed information processing properties of the motivating biological system.

## II. The IIDLE

The IIDLE is a framework inspired by the clonal selection theory of acquired immunity [2], and the spatially distributed and recirculation properties of lymphocytes defined by the physiology of the biological system (for example the lymphatic system and lymphocyte recirculation, see [8] for a review). The motivation for the environment is to consider the information processing principles of a holistic perspective of the acquired immune system (beyond the point-wise cellular level), and to exploit the 'inherent parallelism' of both the architecture (physiology) of the system and of the cellular-based learning (clonal selection theory).

***Motivation**: Exploit the inherent parallelism of the acquired immune system by considering a holistic perspective of the biological system as an inspiration*

IIDLE is not an algorithm, rather it is proposed as a 'systems architecture' for computational intelligence algorithms, drawing on some of the superficial distributed information processing characteristics of the acquired immune system. The focus of these principles is the lymphocyte as the mobile, immutable, and redundant unit of adaptation in the context of a discretised recirculation system. The learning properties

[1] Titled '*Dynamic Resource Allocation in IIDLE*' (Oct. 2005)

[2] http://www.ict.swin.edu.au/personal/jbrownlee/iidle (2006)

of the system are consider rapid (a Darwinian process with learning over somatic rather than general timescales), and to occur in the context of a pathogenic environment that defines the extent of the information to be acquired by the system, and the piecewise manner in which it is exposed to that information (is space and time).

**Distributed:** A population of immune cells that are spatially distributed across the architecture of a host physiology
**Diverse:** The cells of the population are each distinct (spatially heterogeneous), such that different parts of the system can relatively equally address environmental novelty
**Consistent:** Information acquired by the system is made available through the architecture of the system, thus from an external perspective providing a consistent or homogonous effect
**Mobility:** The population of cells are continually in motion around the architecture of the system to facilitate the consistency effect and the diversity effect
**Adaptive:** The cells of the system provide the units of adaptation via a Darwinian-inspired clonal selection mechanism
**Maintained:** The number, quality, and type-densities of cells are managed by local processes in the face finite resources

Figure 1 - Summary of some general immune system features that inspired the proposal of the IIDLE (taken from [4])

The immunological focus is centred on the units of adaptation (immune cells), the system architectural constraints (immune physiology), and the processes to which the cells are subjected (interaction with pathogen and homeostasis). A series of design goals were proposed for the IIDLE inspired by the abstract immune system.

**Environment**: The system is situated in an environment that provides the context for learning and adaptation
**Decentralised**: The broader systemic effects such as learning and memory are emergent from local processes, there is no central point of control or governance for the system
**Regulated**: The resources of the system are managed by local processes within the context of finite resources; such regulation explicitly manages the local space and time complexity of the system, and implicitly at a systemic level
**Triggered**: The changes that occur within the system are made in response to the arrival and nature of external stimulation. Such adaptation occurs when and where such stimulation is perceived by parts of the system
**Redundancy**: Robustness of acquired information is achieved through individual cell redundancy as well as redundancy at the cell-group level. No single cell or relatively small and localised group of cells is critical to the information acquired by the system

Figure 2 - A summary of the design goals for the IIDLE (from [4] and [7])

Such immune inspirations and system design goals were later reorganised into top-down and bottom-up concerns for the system, highlighting an important duality of such a system. The top-down set of concerns considered system-level attributes: external stimulation, learning and memory, situated, consistent, and resilience. The bottom-up set of concerns provided a cellular focus: triggered adaptation, diversity, mobility, decentralised, redundancy.

The IIDLE is presented as a framework of architectural components and information processes that operate in the context of architectural components.

## A. *Architecture*

The architecture of the IIDLE is discrete and relatively simple. A system is situated in an environment that provides sensory input. A system consists of a series of discrete spatial localities that provide an interface to the environment and an internal discrete spatial reference for the system. Within a locality is a data structure (tail) that mediates the relationships between the discrete cellular units of information at that locality. The naming convention for these architecture components is arbitrary and general, abstracted from their immune inspirations of pathogenic environment, tissue, cellular population, and lymphocytes.

**Environment**: A context for the systems triggered (stimulus-response) based learning. The environment represents an abstraction of pathogen, specifically the universe of unknown pathogen patterns to which a given situated system will be exposed. Pathogen arrival provide stimulus to the system which may be controlled or uncontrolled both temporally (when and with what frequency) and spatially (the locality or localities)
**Localities**: An interface between a localised portion of the system and the environment that represents a discretised abstraction of a tissue. A spatial locality provides a point of control over a portion of the system, and connectivity to other parts of the system. A simple directed graph structure is proposed as a ring or torrid as an general abstraction of the circulatory nature of the vascular system used to transport lymphocytes and antibodies.
**Tails**: A tail is a data structure that houses a portion of the total number of cellular information units in the system. Given the mobility properties of cellular units, a population of units in a tail structure may be considered temporally resident. A tail may influence the inter-unit interactions at that locality. The name *tail* was assigned given a graphical depiction of original IIDLE architectural components (for example see [4]).
**Units**: Cellular units are discrete packets of the information acquired by the system, and are an abstraction of B-lymphocytes. As such, lymphocytes may also represent the proposal of patterns that are anticipated to be useful in the future (guesses). A unit of information is immutable, in that it cannot be changed, thus it must be varied during the duplication process. Further, operations on units are atomic (occur holistically or not at all), such that there is no partial considerations. Units are substrate for acquired information (knowledge), and adaptation (learning) by the system.

Figure 3 - Summary of the discrete architectural aspects of IIDLE

## B. *Processes*

Processes represent the active parts of the system, operating on the cellular units at the scope of localities. The processes of the system are simulated in discrete time steps, and the point of control for a process is the locality. Given the homogonous and modular definition of the system's architectural components, the 'scope', that is the localities to which a given process applies, may be varied.

**System Process**: A generic process that applies to units in tails over a finite number of localities. Processes are applied according to regime executed in consistent discrete time steps. This generic process may be specialised to perform a variety of different operations on localities not limited to the processes defined in the IIDLE.
**Movement**: The sharing of information by moving cellular units of one locality with another. Movement is an abstraction of the recirculation of lymphocytes in the vascular system. Unlike the biological system, the movement is bi-directional, the number of moved units is relatively small, and the selection of those units to move is random.
**Decay**: An abstraction of the regulation of lymphocytes. Each cellular unit is allocated a finite energy that is decayed over time. When a given units energy is depleted it is removed from the data structure and discarded. Different decay schemes may be employed such as the constant decrement of unit energy (*conformer homeostasis*), or the locality seeking a local energy equilibrium (*regulator homeostasis*)
**Expansion**: The expansion process is an abstraction of the adaptive properties of the clonal selection theory. Expansion is triggered by external *stimulation* which provides information regarding the environment. Locally resident cellular units at the point of stimulation are *selected* with a bias towards usefulness in the context of the stimulation, and *proliferated* according to a strategy that creates new units with a bias towards being more useful with

regard to the triggering stimulation

Figure 4 - Summary of the processes of IIDLE

The movement process facilitates the important system properties of (1) information dissemination, and (2) information redundancy. From a systems perspective, the dissemination of information fosters a consistent response to the same or similar stimuli across all localities of the system (acquired in one place, available everywhere). From unit perspective, information dissemination provides a way of maximising the probability of the use/reuse of discrete information packets, and thus the continuance of that information in the face of attrition. When information is acquired by the system, more than one copy is created, and each copy may be slightly different variant (different affinity). The copies of the information provide system-wide redundancy of the information. The recirculation and distribution of the redundant information fosters tolerance to loss of individual cells and groups of cells (whole localities).

***Moving Units***: *The movement process disseminates acquired information to the entire system that provides a unified anticipation of the provoking stimuli, and the redundancy provides tolerance to loss or corruption of a portion of the acquired information*

A series of experiments considered the effect of different movement strategies on the systems ability to organise units across localities proportional to the stimulation of those localities. Uniform and Gaussian locality-stimulation strategies were employed, and bi-directional, uni-directional, and stimulation-greedy movement processes were considered. In effect, the principle being considered was that of implicit recruitment of resources, to which the random movement process was found to be as good as any.

***Resource Recruitment***: *The movement process may explicitly or implicitly facilitate the recruitment of resources proportional to need as indicated by external stimulation by then environment*

Another aspect of movement considered was its effect on information dissemination, in an effect that was referred to as horizontal (locality) mixing. In these experiments, a 'useful' piece of information was inserted, and different movement strategies evaluated with regard to how long it took for the information to be duplicated and disseminated across the entire system. Those movement strategies that took into consideration the usefulness of the information when selecting those units to move were naturally more effective at dissemination.

***Horizontal Mixing***: *Measures of the duplication and dissemination of useful information across localities, and ultimately the take-over of the system*

A final consideration of the movement process was the modification to the process to an IIDLE implemented on a computer network. A 'distributed movement' process was proposed [3], where units are collected and transmitted periodically given the communication overheads involved between computers on a network. A given IIDLE system configured one or more localities to act as 'portals' to other systems on the network, providing an interface to other systems. In effect, this proposed modification to system suggested that a given system may be considered a host organism, thus multiple instances on a network may be considered a population of such organisms. The movement between networked system systems thus may be interpreted as the sharing of information acquired in a broader environment between hosts in a population.

***Networked IIDLE***: *A configuration of IIDLE in which each computer has a number of localities in effect acting as a host organism, and a number of such computers communicate acquired information representing a population of host organisms, acquiring and sharing information regarding a broader environment*

The decay process provides a regulation of discrete cellular units at the local level (each locality). Units have 'energy' which is decremented over time, which once depleted, the units are removed. The effect is that those units that are not used, are removed from the system, and those that are, create progeny that may put pressure on those unused units. Two decay strategies are proposed: (1) the constant decrement of energy called *conformer homeostasis*, and (2) a variable decrement of energy based on the local energy capacity called *regulator homeostasis*. Conformer homeostasis allows the local resources to be controlled by the amount of external stimulation. More stimulation results in the creation of more units, which increases the population size. Given the constant energy decrement, the local population will take a while to decrease in size. Alternatively, if a locality is not stimulated for a while, its local unit population will decay away to nothing. Thus, although the approach may provide a closer match to the immune inspiration, there are large oscillations in behaviour. The regulator homoeostasis decay process requires the specification of an ideal (desired) energy for each locality. Each application of the decay processes requires the local population of units be assed with regard to the energy total. Units are then decayed uniformly in an effort to return the local total energy toward the ideal (point of energy equilibrium). Unlike the conformer approach, the regulator homeostasis maintains a stable population of units, although in times of excessive stimulation, the amount of attrition may result in the loss of acquired information. A hybrid of the two approaches is proposed to both maintain a minimal energy level, although allow expansion of the population when required.

The expansion process provides the adaptive capabilities of the system. The process is triggered by the stimulation of a locality (or localities). Stimulation may or may not be controlled by the system, and exposes information about the environment to the units of the stimulated localities. Stimulation was envisaged to be a random event, where localities of the system are sporadically (time and space) exposed to the environment. Stimulation results in two internal processes, the selection of units that are useful with regard to the stimulation, and the creation of new units that are expected to be useful with regard to the stimulation (and selection) in the future. The expansion process, specifically the information selection and information creation steps are sufficiently general to facilitate the implementation of a wide array of population based probabilistic selection and sampling techniques.

### C. *Systems Engineering*

The IIDLE has a strong systems engineering and systems architecture focus. This is exhibited in the generality of the data structures and information processes. The proposed system is far removed from the so claimed biological inspiration of the acquired immune system. Instead of reasoning by analogy, the components, processes, and expected behaviours of the system are reasoned by convenience.

***Systems Engineering**: In computer science, the concern of the system components, system architecture, and integration of systems to meet information processing needs*

One work in particular provides an implementation specification for the platform [3], highlighting software engineering principles and software tools, including: platform independent implementation in Java, modular and extensible design, object oriented design principles, use of open source libraries and datasets, tuneable via a scripting engine, designed to be multithreaded from the ground up. A series of so called 'additional design goals' were proposed, that although may be suitable, are proposed in the context of systems engineering. These include: distributed rather than centralised information processing, simple and lightweight framework, modular and extensible, scalable, and configurable.

A systems engineering perspective to designing an immune inspired distributed information processing perspective may be a desirable research goal. The concern is that such a perspective does not match the proposed spirit of the project: computational intelligence in the field of artificial immune systems (as proposed in [7]). From this perspective, IIDLE may represent a potential *outcome* (endpoint) from studying the computational and information processing principles of the acquired immune system. IIDLE represents a top-down (systems perspective) of a project goal that was proposed to be addressed in a bottom-up manner. As such, it may be a better suited project in the field of Autonomous Distributed Systems (ADS) [14], Autonomy Oriented Computing (AOC) [13], or Autonomic Computing [17], rather than the field of computational intelligence artificial immune systems [15].

## III. SOME THEMES

Given the identified systems perspective of the previous section, one may attempt to disentangle some of the interesting computational intelligence themes from some of the work completed to date. Some natural areas include the design goals and their relation to the information processing. For example, the ideas related to information dissemination and information redundancy typified in the recirculation of lymphocytes, and abstracted to the movement process. As will be shown, such base level (bottom up) information processing concerns have already been considered and addressed in a series of adaptive models and algorithms. Given the systems engineering perspective, a top-down approach to the development and the *application* of the system was taken. The latter is the concern of this section, the identification, and disentanglement of potentially interesting application-based information processing from the IIDLE project that may or may not find meaningful integration with the field of artificial immune systems.

***Perspectives of the Environment**: The capability of the system to both consider and integrate multiple and concurrent different perspectives of the environment*

The first identified principle is that of the immune systems ability, and IIDLE desirability to consider and integrate different perspectives of the environment concurrently. Firstly, from the acquired immune system perspective, the system has specialised tissue systems to address specialised interfaces with environment (injection, respiratory, etcetera). These systems are exposed to very different 'perspectives' of the environment, and specialise as such, although the res knowledge acquired at one location is made available across the entire system (recirculating lymphocytes and effector cells and antibodies).

The IIDLE considers this effect in a number of different ways: (1) control of the type of information from the environment, (2) the perception of the environment, and (3) the response to stimulus.

***Varied Stimulation**: The systems control over (1) what information from the environment to which it is exposed, and (2) where in the system it is exposed to the varied information*

In controlling and varying the stimulation of the IIDLE, an asymmetric environment was created, which resulted in an asymmetric acquisition of information. Stimulation was controlled and varied in a number of different ways include (1) the evaluation function of units, (2) the source of evaluation. Units may be interpreted as solutions in and of themselves, and thus may be evaluated independently of each other. The context of that evaluation may vary, for example, different metrics may be used to interpret a solution. Experimental examples include the different TSP objectives [7], the different objective functions [5], or in the human operators assessing the aesthetics of solutions [6]. In all three cases, the intent of the system was to holistically (all localities) to solve a specific optimisation problem, although to do so, the system was expected to exploit and integrate *different information* about progress towards the solution.

***Varied Perception**: The systems control over the ways in which the environment is perceived, thus influencing the way in which discrete units are evaluated*

A variation on controlling the information the system is exposed to by the environment, is to control the perspective by the system of the same information from the environment. Two examples of the controlled variation of perception include (1) the parts of a unit that are made available to an evaluation function (in a linearly separable continuos objective function [5]), and

(2) the proposal of different localities 'views' of the problem space (constrained problem subspaces). As in the case of the varied stimulation examples, the holistic system was intended to solve a specific problem, although in this case by exploiting and integrating *different perspectives* of the environment. In both of these cases (varied stimulation and perception), the systems used complementary objectives and perspectives. What was not considered is important perhaps for any future investigations is the assessment of a systems capability to exploit and integrate conflicting objectives.

***Varied Response****: The systems control over the ways in which the discrete units respond to stimulation by the environment (proliferation strategies)*

A final important interpretation by the IIDLE project of the 'perspectives of the environment' principle is that of controlled variation over the systems response to the same information. Control over response is implemented in the selection and more importantly the proliferation step of the expansion process. This processes provides a generalised framework for a selectionist sampling procedure (inspired by clonal selection, population based). The generalise selection process allows a variety of different selectionist-based computational intelligence algorithms to be implemented ([3,5-7]) not limited to variations of the clonal selection algorithm, genetic algorithm, particle swarm, ant colony, random search, and learning vector quantisation. Thus, an IIDLE is intended to solve a specific optimisation problem by exploiting and integrating the results of a variety of different response mechanisms.

***Partitioned and Mixed Control****: The consistency of the control over the (perspective) interaction with the environment (information, perception, and response) may be maintained in a partitioned configuration, or discarded in a mixed configuration*

Control over the information, reception of information, and the response to information is layered over the IIDLE architecture, with a single locality representing a unit of scale. Thus the platform considered the partitioning (consistent) and mixing (inconsistent) of localities according to these three different controls of environmental interaction. The mixed configuration represents an extreme configuration in that the system is expected to exploit and integrate the aspect being varied (information, perception, response) where the extent of variation is available at each point of the system. This configuration may assist in integration, although may dampen the effects of any single varied scheme, alternatively the partitioned configuration is expected to have the opposite effect of improved specialising for a given scheme in a partition with dampened integration.

***Exploitation and Integration****: Partitioning promotes exploitation of a varied scheme at the expense of integration, where as mixing promotes integration at the expense of integration*

Another aspect of the IIDLE is that of information redundancy, facilitated by cloning (creating more than is locally required) and the mobility of units (recirculation). Redundancy of information fosters robustness and fault tolerance of the information acquired by the system. The redundancy of the system was investigated by removing entire localities of the system and observing the effect on learning [6,7]. Also included in this study in this investigation was the dynamic increase in the number of localities and the observed effect on learning tasks. These experiments were based on the premise that a locality provides capacity for information in the system that may be manipulated dynamically. Further, once information is acquired by the system (information that is useful and has been disseminated) it is difficult to remove, in effect the entire system must be dismantled. Thus, in exploiting the principles of (1) multiple perspectives, (2) robustness via redundancy, and (3) variable system information capacity, IIDLE was phrased as a distributed ubiquitous information-processing platform.

***Distributed and Ubiquitous Computing****: A phrasing of IIDLE that considers the ability of the system to exploit and integrate multiple perspectives of an environment, using a knowledge medium that is robust and pervasive provided by redundancy, which is always on, and whose information capacity may be dynamically scaled*

This phrasing of IIDLE clearly fits into the 'systems engineering' philosophy, although the applications of the phrasing are interesting (and potentially novel) nonetheless. In essence, a large-scale implementation of IIDLE provides a distributed information resources that may be consumed and produced to by automated processes (such as algorithms), and human operators. The latter case may be exploited for applications such as the concurrent exploitation of varied human experts on a consistent and shared information substrate. An example of such an application is a large-scale optimisation process, where the information substrate represents samples in the problem space. All manner of environment-to-information controls may be manipulated by a human operator with domain knowledge (such as information provided to the sample, perception of the information, and the re-sampling process). The feasibility of such a system is unknown, although it suggests at the nature of the '*environmental perspectives*' principle of the system when pushed to an extreme.

## IV. IIDLE AND THE HIERARCHICAL FRAMEWORK

The hierarchical framework integrates the clonal-selection based information processing of pathogen by the acquired immune system at three different scales, and connects a series of adaptive models and inspired algorithms [10-12]. The IIDLE was proposed before the hierarchical framework and related work, thus one may consider the relationship of these two streams of research.

***Top-Down****: The IIDLE is a top-down realisation of the distributed information process properties of the acquired immune system, concerned with the broad capabilities and application of those capabilities.*

IIDLE is concerned with the systems engineering of a immune inspired distributed learning environment. As demonstrated, the framework is concerned predominantly with the application of the proposed framework, exploiting the capabilities of the systems to exploit and integrate different perspectives of a problem domain. The framework is concerned with the physiology and theoretical models for describing biological processes of the acquired immune system. As has been demonstrated in previous work, the framework is concerned with the reduction of aspects of mammalian immunology into adaptive and cognitive models, and into inspired algorithms at attempt to realise identified characteristics.

***Bottom-Up****: The hierarchical framework and related adaptive models and algorithms are a bottom-up realisation of the distributed information processing properties of the acquired immune system*

Given the high-level perspective of the IIDLE, the immunological inspiration takes only the vaguest distributed information processing properties of the biological system into consideration. Specifically, the spatially spaced population of cells throughout a host organism, and the recirculation properties of cells between spatial compartments. Thus, the IIDLE may be classified as a tissue-based model in the hierarchical framework. The locality-tail-unit architecture with the movement process roughly resembles a lymph-node architecture realisation of a recirculation algorithm. Although, the fact that the model does not consider the constraints of the scales above and below the tissue level, or many of the specifics of the tissue level, the IIDLE may be considered a horizontal adoption of the tissue level of the framework.

***IIDLE as a Horizontal Adoption****: The IIDLE may be considered a horizontal adoption and systems realisation of a tissue-level model of the hierarchical framework of the acquired immune system*

The IIDLE's horizontal realisation of the tissue level of the framework makes assumptions regarding the information processing capabilities of the biological system. The assumptions are centred on the discrete information redundancy and the distributed capabilities of exploitation, integration, and recruitment. The model is then applied on problem domains without (1) the identification of these properties in the motivating biological system, or (2) the verification of these properties in simplified models and algorithms. Thus, from this perspective, the hierarchical framework provides the bottom-up complement to the IIDLE. The framework provides the rigor required to support the presumptions made by the proposal of IIDLE. Alternatively, IIDLE represents an abstraction of the identified, abstracted, and demonstrated information processing properties of the acquired immune system.

***Assumptions****: The IIDLE makes assumptions about the distributed information processing capabilities of the tissue-level of the acquired immune system, which the framework attempts to provide the rigor to support.*

Given the top-down methodology used in the development of the IIDLE, much of the detail of the inspired system is not considered. This detail includes concerns such as information management (homeostasis and the decay), a consistent naming convention, and the information processing mechanisms for information transmission (the movement process), aspects which are considered directly in the hierarchical framework. Thus, work towards integration of the two thrusts of work may involve embodying the abstracted information processing models and algorithms from the hierarchical framework into the IIDLE. IIDLE this represents a holistic realisation of the information processing a the tissue level, integration with the tissue level may involve realising many if not all of the algorithms into a single model.

***Holistic****: The IIDLE represents a holistic realisation of the information processing models and algorithms of the tissue tier, thus integration may involve the implement of many if not all of the piece-algorithms of that tier.*

The proposed implementation of IIDLE on a computer network and the properties of distributed movement perhaps provide the basis for the host (population) level of the hierarchical framework. Further, the proposal provides the broader context in which to consider the aggregation of the localities of the IIDLE as single system, at a single-host level of abstraction of the system. This connection highlights that the application-centric development of IIDLE raises questions regarding the information processing capabilities of the motivating biological system, questions that are considered and evaluated by the hierarchical framework (the assumptions argument). Thus, the IIDLE may provide an application motivation for the models and algorithms that are developed in the context of the hierarchical framework, bridging the relationships between (1) the biological system, (2) the information processing abstractions, (3) the algorithms, and (4) suitable application domains.

## V. DISCUSSION

The application centric perspective of IIDLE postulated at the suitability of the information processing properties of tissue-level algorithms of the acquired immune system without explicitly identifying and verifying those information-processing capabilities. The proposed domains were unified under the common theme of (1) the systems ability to exploit and integrate different perspectives of a domain, and (2) to do so in the face of innate discrete information redundancy, providing robustness to failure and information-loss in the processes. The hierarchical framework did not explicitly consider the system-level concerns, although similar concerns of information sharing and spatial-dissemination of information were considered (for example see [9]).

The IIDLE gives perspective to the bottom-up hierarchical framework, highlighting perhaps the deficiency of vision for the developed models and algorithms. A deficiency that may be overcome by a horizontal consideration of the holistic models in the context of engineering (or proxy-engineering) application problem domains. The top-down and bottom-up perspectives complement each other, the former suggesting broad suitability, and the latter providing the rigor to support such suggestions.

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