Bio-inspired Model for Behavior Emergence: Modelling and Case Study

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Abstract

Large scale networks such as computational Grid promise a distributed computing infrastructure that can provide globally available network resources. Their size and complexity continue to increase and permit an almost ubiquitous availability of resources; users access to network resources irrespective to their location. These distributed systems need to be highly flexible, self-organizing and adaptable in order to cope with the dynamically changing environment. In this paper, we propose a models of holonic multi-agent system inspired by the Human immune system for behavior emergence. Our aims is to provide, from the computational viewpoint, models offering powerful and robust information processing capabilities for resource allocation in large scale network. We then discuss the implementation and present results to show that inspired models exhibit self-organization with support for mobility, flexibility, and adaptability to users and network condition changes.

1. Introduction

Current computer systems are used in diverse and complex ways. They tend to evolve towards totally distributed knowledge. However, the way in which they have typically been constructed is often very inflexible and centralized[1]. New operational model to use resources efficiently and reduce the need for the resource management is required. In this paper, we present an autonomous decentralized and self-organizing approach inspired by the immune system as a model of resource allocation in large scale network such as computational Grid. The immune system has a useful set of organizing principles that guide the design of scale, adapt and efficient enough networking model to bring answers to some large scale networking challenges.

Biological principles have been exploited in a variety of computationally based learning systems such as artificial neural networks and genetic algorithms[2][1]. Also, the emergence of complex collective behavior from the local interactions of simple agents is illustrated by many natural systems, like ant' colony, bee' colony[3, 4, 5, 6], that exhibit capabilities of complex distributed solving. The artificial immune system receive similar attention like other biological-inspired approaches. They are a great source of inspiration in many different areas including network security[7, 8, 9], parallel processing[10], robotic[11] and many others[12, 13, 14, 15].

Artificial immune system is a highly distributed system based on the principles of the natural immune system. It provides an excellent and adaptive model at the local level and the useful behavior emerging at the global level. Two models of natural immune system have been proposed. The first one by Jerne and we call it the First Natural Immune Model (FNIM)[16, 17]. The other one has been proposed by Varela and Stewart, we call it the Second Natural Immune Model (SNIM)[18]. In FNIM, the immune network is made up of B-cell clones that are connected through idiotypic interactions. The participation of T-cell is typically neglected or ignored. In SNIM, the activation of B-cells explicitly dependent on co-operation with activated T-cells.

In artificial intelligence, to think immunology, it is sometimes to think Multi-Agent System (MAS). To think MAS, it is to think modelling and simulation. Thus, these similarities make MAS the natural bridge between the world and that of data-processing modelling and simulation. Holonic Multi-Agent System (HMAS) is becoming an important issue. It involves a constructive approach, defined by the combined behavior of entities that it composes. If the combined behavior of a group of entities is different from the aggregate behavior of the entities, the emergent behavior is said arise. The Holonic multi-agent system enables the construction and design a very complex systems that are highly distributed, and adaptable to changes in the environment[19]. HMAS designers are increasingly using metaphors from social, geological, biological and economic organization in order to structure their systems[20].

In this paper, we propose HMAS models inspired by the FNIM and SNIM to model and solve complex problem. The immune response (i.e. behavior) emerges trough co-operation between its entities. In this work, we propose two organizational forms of HMAS inspired by the FNIM and SNIM to behavioral emergence in dynamic distributed system. We call them Decentralized Holonic Multi-Agent System (DHMAS) and Hierarchical Holonic Multi-Agent System (HHMAS) respectively.

The rest of the paper is organized as follows. Section 2 presents inspired holonic multi-agent models. In section 3, we present a study case applying the proposed models for resources allocation problem in computational Grid. Conclusion is given in section 4.

2. Holonic Multi-agent system models

The immune system is distributed throughout the body and function continually using its own network lymphatic vessels with no central organ to control it [14, 21]. The entities of immune system are self-organizing and function continually to learn and remember from past and adapt to environment changes[21]. In order to study emergent properties and behaviors in these systems, it is necessary to study their organization. In this section, we present the proposed holonic agent-based models.

2.1. The first model

Jerne [16] has proposed the concept of the idiotypic network. It states that B-cells are not just isolated, but they are communicating to each other through stimulation/suppression chains that form a large-scaled network, and work as a self and non-self recognizer[11]. The key portion of the antigen recognized by the antibody is called an epitope (i.e. antigen determinant). The key portion of the corresponding antibody that recognizes the antigen determinant is called a paratope such as shown in figure 1. Each type of antibody has its own antigenic determinant, called idiotope. In fact, an antibody is recognized as an antigen by other antibodies. This relationship between B-cells is called the second generation idiotypic network[17, 11, 18]. The participation of T-cells is typically neglected or ignored.

In this model, the idiotope of an antibody is recognized by another antibody as an antigen. Such as depicted in figure 1, the immune system eliminating foreign antigens is offered by the entire system in collective manner. In this way, we model Decentralized Holonic Multi-Agent System (DHMAS), inspired by the FNIM model, as a federation of autonomous B-agents (B-cells). This structure assumes that

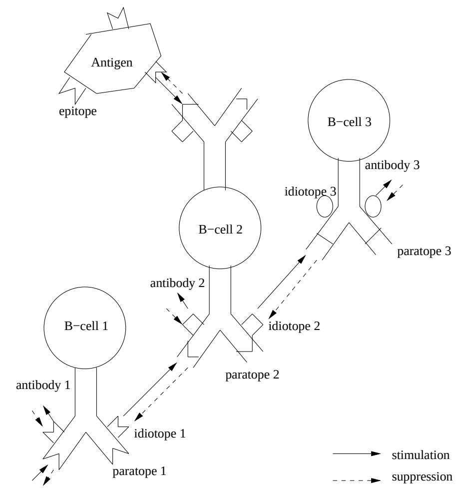

Figure 1. The Jerne's Idiotypic Network

the B-agents are autonomous agents with their predefined architecture and the DHMAS is just a new conceptual instantiation of the same generic agent architecture. In fact, is not represented explicitly, but it is realized through cooperation among B-agents[19, 22].

In this model, each B-agent can reason, communicate and collaborate with each other. It allows B-agent to be aware of other by sharing tasks that are commonly undertaken. B-agents cooperate equally rather than being assigned subordinate and supervisory relationships[19]. The communication and co-operation among B-agents, to resolve a particular problem (i.e. achieve a goal or objective) is achieved via passing messages or shared information. This model provides the necessary flexibility and robustness.

The objective of this model was that a set of B-agents found and carried out tasks spread along a given environment. The behavior of each B-agent had to be stimulated and/or suppressed by other B-agents. Thus, the behavior (i.e. immune response) emerges through interaction between several H-agents, each with their own group of B-agents. Figure 2 shows the organizational structure of H-agent.

2.1.1 H-agent building

To build Holon agent (H-agent), B-agents establish the relationships between them. Such as depicted in figure 3, the paratope describes the condition under which a B-agent is stimulated and the idiotope describes the reference to stimulating B-agents in its environment and the degree of stimuli (i.e. affinity)[11]. Affinity corresponds to the adequacy with which two B-agents bind. B-agent will co-operate simply with which it can have a connection or co-operation. If several B-agents answer the criteria of co-operation, only

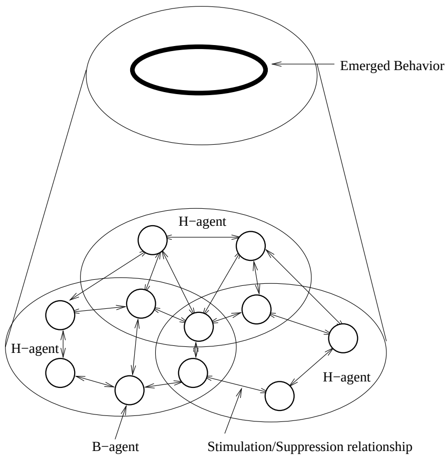

Figure 2. Modelling DHMAS as a group of B-agents

Figure 3. The B-agent description

most influential is taken into account. Affinity changes dynamically as B-agents learn the significance of the relation through interaction.

These H-agents emerge through interaction between B-agents according to the stimulation/suppression relationships. In fact, several H-agents emerge through dynamically adding and removing B-agents to and from the H-agents. Figure 4 presents this processus, named Metadynamics function of immune system. By adding and removing the B-agents, the system creates behavioral diversity. B-agent may clone, die or move randomly and may establish a new stimulation/suppression relation with other B-agents. In fact, a new H-agent may be created or other may be modified according to dynamically changing environment. With this function, the idiotypic network creates diversity of behaviors and can re-organizes at run-time.

2.1.2 Behavior emerging

For a collective behavior to emerge, a set of B-agents must co-operate with each other and with their environment. In fact, the behavior will being emerged through interactions between B-agents in the H-agents. B-agents work as a self and non-self recognizer. Thought, these relationships, the idiotope of B-agent is recognized by another B-agent as an Antigen. In fact, B-agent is considered to be both a service provider and a service requestor. Each B-agent interacts with each other through stimulation/suppression chain

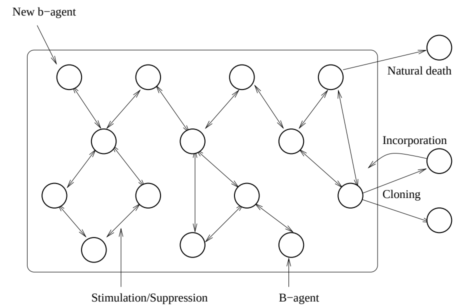

Figure 4. The Meta-dynamic Function of DHMAS

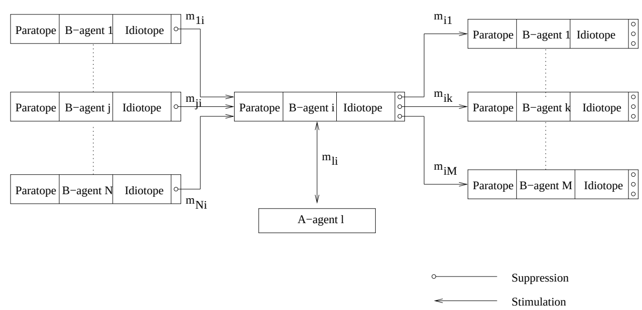

Figure 5. The generalized view of DHMAS

until the behavior is emerged. Figure 5 shows the generalized view of B-agents within the idiotypic network. The B-agent i is stimulated by N B-agents and suppresses M B-agent, such as depicted in the left and the right of the figure respectively. m_{ji} and m_{ik} denotes affinities between B-agent j and i, and between B-agent i and k, respectively. The affinity means the degree of stimulation or suppression. m_{li} denotes the affinity between an antigen l and a B-agent i. The antigen represents the current environment conditions.

The affinity m_{ij} is a parameter that represents the priority between B-agents. It help to distinguish between B-agents that can satisfy certain conditions. In fact, the H-agents can re-arrange at run-time by changing affinity values based on the previous experience. This mechanism allows the B-agents to learn from results in order to co-operate in the most efficient way. The learning mechanism depend on the problem to be resolved.

2.2. The second model

In the FNIM model, proposed by Jerne[16], T-cells help is never a limiting factor for B-cell proliferation or production of antibodies. Stewart et al.[18] have proposed an amplified version of the FNIM, named SNIM (i.e Second Natural Immune Model). In this model the main propo-

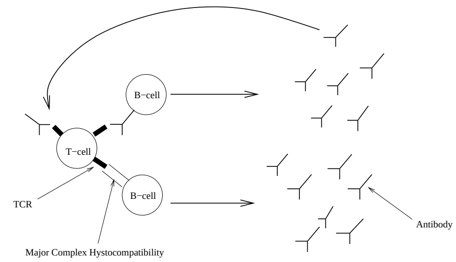

Figure 6. Third Generation Immune Network

sitions in FNIM still hold, but some additional ones was introduced to describe the dynamics of T-cell clones and their co-operation with B-cell clones and the antibodies they produce. According to SNIM, the activation of B-cells is explicitly dependent on co-operation with activated T-cells[15]. The production of the antibodies by the B-cells mediates idiotypic interactions between them, and control their induction. In fact, circulating antibodies are the only inhibitory influence on T-cell activation and growth such as depicted in figure 6. A bounded dynamics of the T-cell activity can be achieved if and only if their receptors are integrated into the idiotypic network.

The dynamics properties of this model are dependent on the two modes of B-T-cells co-operation. In the case where both lymphocytes clones will grow exponentially. The seconds mode occurs when a B-cell clone co-operates with a T-cell clone trough direct membrane Antibody-TCR (T-Cell Receptor) interaction. In this case, the antibodies produced by the activated B-cells specifically recognizes the TCR of their T-cell counterparts. Since free anti-TCR (i.e. antibodies molecules) are inhibitory for the T-cells activities. This equilibrium is stable, because if the B-cell activity were to increase, the additional anti-TCR would inhibit the T-cells, and the reduced T-cell would decrease the B-cell activity back to the equilibrium point.

An other class of soluble mediators named cytokines, realized by T-cells to communicate with B-cells[15]. In this way, we model Hierarchical Holonic Multi-Agent System (HHMAS), inspired by the SNIM model, as a moderate group of autonomous agents[19, 22]. In this model, the T-agent is a head that represent the super-holon. This model allows an explicit modelling of holons, a flexible formation of holonic groups, and scalable degree of autonomy of the participating agents. Figure 7 shows this model.

The immune response is emerged through interactions between B-agents and T-agents in the H-agents. The HHMAS is identical to the DHMAS, will the exception that a helper agent (i.e. T-agent) that undertakes collective tasks is necessary. In this model, B-agents give up only part of their autonomy to the T-agents (i.e. super-holon). For example, T-agent may range from purely administrative and direc-

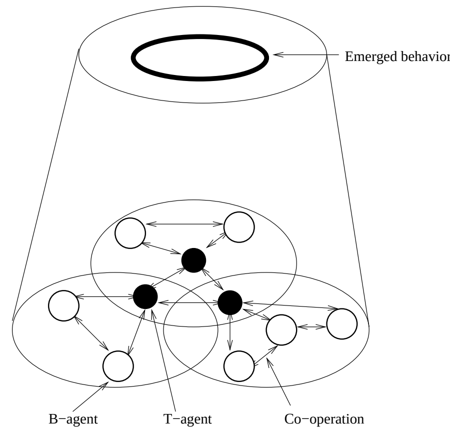

Figure 7. Modelling HHMAS as a moderate group of autonomous agents

tives tasks to the B-agents in the Holon, such as planing and negotiating, removing and incorporating new B-agents.

3. Case Study: Resource allocation in Grid Computing

The immune system is self-organizing; it able to change its structure at run time and adapt it as their environment changes. It uses learning and memory to solve recognition and classification tasks. It can be seen in the literature[15], that the immune system is particularly interesting for solving problems in distributed and dynamic environment. It was our aim to provide an agent-based models that can be used in a wide source of potential applications and inspiration for immune-based approaches. One of these applications is the resource allocation in large scale network such as the computational Grid.

As described above, we have proposed two models of holonic multi-agent systems inspired by the FNIM and SNIM models. In these models the required behavior (i.e. immune response) emerges trough stimulation/suppression relationships between its entities. However, it would select which model was pertinent to such environment in function of requirement resources and the number of B-agents in H-agents. In this model, the grow of B-agents in H-agents creates a bottlenecks around T-agents. In one hand, the HHMAS should be used in the field where the information that is modelled is stable for longer periods of time. In another hand, it may be appropriate to use DHMAS if the information is dynamic. In Grid computing, DHMAS is more appropriate than the use of HHMAS. It is required to be self-organizing with inherent support for mobility, scalability, and adaptation to short and long term change in user requirements and network resources. We present in details the application of DHMAS for resource allocation in Grid computing.

3.1. Related work

A resource is an entity that provides state and functionality to be utilized by other entities. Resources are divided into two basic categories[23, 24]: system resources and application resources. System resources are bound to specific hosts, representing hardware devises (e.g. disk) or logical system objects (e.g. socket). Application resources are software entities, possibly mobile, which are managed by an application.

Grid computing are wide-area distributed environments that differ from conventional distributed computing by their focus on large-scale resource sharing[25, 26, 27]. A fundamental aspect to allocate a resource in a Grid computing is done via interaction between the provider and the user of the resource. We can distinguish between two resource allocation paradigms[28]: client-server and mobile agent paradigm. In client-server paradigm, the user know in advance the server sites where it can allocate the required resources. From there, other sites containing interesting resources can be found. The intrinsic inefficiency of this approach is evident; it requires a high completion time and the availability of network connection[29, 28]. In the mobile agent based paradigm, the user initiates a request without specifying any destination server. Mobile agent become a novel paradigm of building distributed software systems[30, 31, 32, 33, 34].

Several solution based on mobile agent have been proposed that address some issues of resource management in large scale network [35, 23, 36]. Schwartz [37][38] has proposed a probabilistic approach; the resource information is disseminated to a reasonably small neighborhood of any agent in the network, so that during searches, the required resources can be found using simple random probes. This approach support fair access among competing information between providers. Michael Moore and al. [39] have proposed a decentralized and self-organizing discovery mechanism in Peer-to-Peer network that is modelled as a population of agents linked together by relationships. The agent represents the resource information. The discovery messages are forwarded along these relationships, attending to reach the agent that would satisfy a particular discovery query. Another approach have been proposed by Kyungkoo Jun and al [40]. It allows the individual nodes to gather information about resources in wide-area distributed system based on mobile agents. Twine [41] is resource discovery system for pervasive computing environment. It uses a set of resolvers Twine nodes that organize themselves into a network in order to route resource information to each other, and collaborate to resolve client queries. Cameron Ross Dunne [42] has proposed a mobile agent approach for network resource discovery in peer-to-peer networks. Another approach use agent-based service discovery for resource management in metacomputing environment[43]. In [25] a Multi-agent system called AgentScape, that can be employed for an agent-based approach to integrate and coordinate distributed resources in a computational Grid. Jun and al. [44] are proposed an algorithm and a model for distributed awareness for dynamic assembly of agents monitoring network resources. Andriana Iamnitchi and al. [24] are proposed a Peer-to-Peer approach for resource discovery in Grid environment. They propose a study of resource discovery problem in a resource sharing environment that combines the complexity of computational grid and of dynamism of Peer-to-Peer network. In our work, we present an autonomous decentralized and self-organizing approach inspired by the immune system as an approach for resource allocation in computational Grid.

3.2. Agent-based approach

In our agent-based approach, resource allocation is abstracted to resource dissemination and resource discovery. The resource dissemination provides information about site resources or a pointer to a source of resources. The resource discovery is the mechanism by which the user or application find the required resources[45]. In the dissemination process, each B-agent create a mobile B-agent that move randomly in the network and disseminate its information resources. Hence, each B-agent has a partially or completely knowledge on the available resources. In fact B-agents learn more information about other B-agents. Figure 8 presents the agent-based architecture for resource management and allocation. Each static B-agent is considered as a peer agent. It acts as both client and server learn about a subset of other B-agents, as well as a subset of available resources and collaborate to resolve client queries. In fact, when the first B-agent receives the request, it may contact other B-agents until the required resources is found.

3.2.1 Resource dissemination process

According to DHMAS described above, B-agents establish relationships between them and interact in order to form H-agents. These H-agents emerge through interaction between B-agents according to the stimulation/suppression relationships. In fact, several H-agents emerge through dynamically adding and removing B-agents to and from the H-agents.

To build H-agents, mobile B-agents move randomly and update each peer agent by information resources of its creator. The mobile B-agent come back to the home site when it has fulfill its objective. The resource information is being disseminated at every peer B-agent that the mobile B-agent

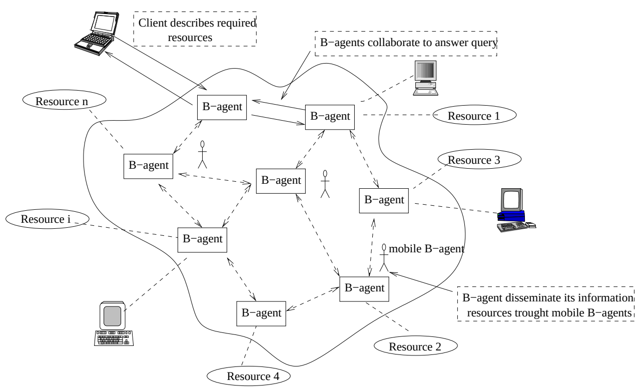

Figure 8. The architecture of our agent-based system

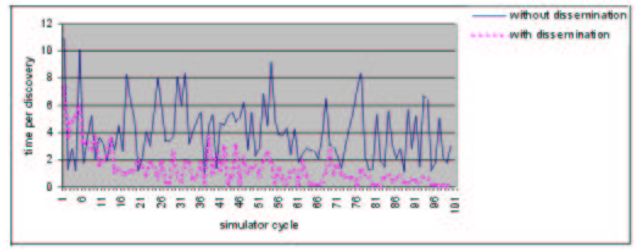

Figure 9. Discovery response per simulation time

visits. Mobile B-agents can create replications to themselves, passe tasks to this clones that walks randomly to further sites. Each clone adopts the same behavior until no next sites exists or after fulfilling its objective. This would allow mobile B-agents to cover a much wide area of information space in a shorter time. This approach is more promising in an large scale network, such as computational Grid, where resource might dynamically and unpredictably change and a complete knowledge of this change is difficult to be obtained. It is well known that random walks can converge extremely fast[46, 47, 48].

3.2.2 Resource discovery process

The resource discovery is based on the co-operation between B-agents in H-agents. A B-agent send the request with the required service (i.e. set of resources with QoS). If none of H-agents cannot provide the required service, each B-agent in turn query other B-agents that it has a relationship, with until the required resource is found. The affinity m_{ij} is a parameter that represents the priority between B-agents in resource discovery process. It help to distinguish between B-agents that can provide the required service. The affinity is adjusted based on the degree of satisfaction of user and the changing of resource.

3.3. Experimental result

Our simulator was implemented by NS2[49]. In one hand, a single mobile B-agent moves randomly between sites, disseminates the resources, and comes back to home site if all sites have being visited. In another hand, the resource discovery process may be distributed trough the B-agents. Each B-agent know about some subset of resources and other B-agents. To simulate and evaluate our proposed approach for distributed resources discovery, the client resides in a site, and represents the user that wants to reserve a certain quantity of resources. Each one of which has an acceptable quality of service. The desired objective is to find a group of B-agents that can provide the resources with a quality of service less than or equal to those specified. At each simulation time the client send a query in order to find the required resources. We compare to strategies: with and without dissemination. The figure 9 shows the discovery per time. For each discovery, this represents the average number of simulator cycles used to fulfill a discovery. This primary result shows, in one hand, that with full resource dissemination protocol the required resources can be found in a reasonably number of B-agents. In anther hand, with no resource dissemination protocol, each B-agent has no knowledge of the resources provided by other B-agents. The discovery process may traverse a large number of B-agents.

4. Conclusion

The increased network connectivity and the requirement to access to network resources through Scale-Internet make the resource allocation the most important factors in distributed computing. In this paper, we have presented an autonomous decentralized system based on mobile agents and inspired by the immune system for resource allocation in large scale network such as the computational grid.

Our further studies will proceed towards two main directions. On the one hand, we are currently completing this approach in terms of adaptation of H-agents to dynamically changing environment. In fact, the H-agents can re-arrange at run-time by changing affinity values based on the level of user preference and dynamically change of resources. This mechanism allows the B-agents to learn from results in order to use network resources in most efficient way. On the other hand, we are trying to extend and formalize the protocol in order to prove its correctness and its vivacity.

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