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Formal specification of an immune based agent architecture

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ABSTRACT

The natural immune system is a subject of great research interests because it provides powerful and flexible information processing capability as a decentralized intelligent system. The immune system constitutes an excellent model of adaptive cooperation at the local level and of emergent behaviour at the global level. These concepts can be applied in the Multi-Agent Systems field where autonomous agents interact in order to solve a common goal. There exists several theories to explain immunological phenomena and software models to simulate various components in the immune system. This paper presents a formal specification of the idiotypic network theory viewed as an agent architecture. The specification gives a precise and non ambiguous description of this architecture which is validated through the automatic generation of traces and interesting properties are proven. This specification constitutes a starting point for understanding, reuse and implementations of this architecture. The approach is illustrated with the robot soccer simulation example.

1. Introduction

The natural immune system is a subject of great research interests because it provides powerful and flexible information processing capability as a decentralised intelligent system. The immune system constitutes an excellent model of adaptive cooperation at the local level and of emergent behaviour at the global level. These concepts can be applied in the Multi-Agent Systems field where autonomous agents interact in order to solve a common goal. There exists several theories to explain immunological phenomena and software models to simulate various components in the immune system (Suzuki and Yamamoto, 2000).

These artificial immune systems (AIS from hereon) are typically defined in an informal way and applied in an ad hoc fashion. As stated in Timmis (2007), Aickelin and Dasgupta (2006), de Castro and Timmis (2003) the AIS domain needs foundational works in order to clearly define models and frameworks that allow understanding and exploitation. The need is even more critical in the case of idiotypic networks chosen in this paper as it is a controversial subject even for the biologists (Timmis et al.,). Consequently, system designers have been unable to fully exploit the existing models commonalities and specialise or reuse them for specific problems.

The contribution of this paper is to propose a formal specification approach of an idiotypic network based architecture based upon the composition of Object-Z and statecharts. This specification allows a precise and non-ambiguous description of the architecture. Moreover, using software tools that enable model checking and theorem proving one can gain understanding on the architecture behaviour. Such a specification allows to fully exploit the idiotypic network models and facilitate its reuse. The use of the presented architecture is illustrated on a robot soccer example.

The basic components of the immune system are macrophages, antibodies and lymphocytes. Lymphocytes are the cells maturing in the bone marrow and produces antibodies from its surface. The antibody recognises and binds to specific type of antigens (foreign substances invading a human). The key portion of antigen that is recognised by the antibody is called epitope, which is the antigen determinant. Paratope is the portion of antibody that corresponds to a specific type of antigens. Once an antibody combines an antigen via their epitope the elimination process can begin. Recent studies in immunology have clarified that each type of antibody also has its own antigenic determinant, called an idiotope. This means that an antibody is recognised as an antigen by another antibody (Farmer et al., 1986). Based on this fact, Jerne proposed the concept of the immune network, or idiotypic network (Jerne, 1974), which states that antibodies and lymphocytes are not isolated, but they are communicating with each other. The idiotope of an antibody is recognised by another antibody as an antigen. This network, called idiotypic network, is formed on the basis of idiotope recognition with the stimulation

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and suppression chains among antibodies. The approach presented in this paper is based on this interpretation of the immune system (Table 1).

This paper is organised as follows: Section 2 presents the principles of Immune System and AIS. Specifically the background concerning an architecture inspired by idiotypic networks is presented. Section 3 presents our formal specification notation and the specification of the architecture its analysis and an example. Section 4 presents some related works. Eventually, Section 5 concludes.

2. AIS background

2.1. Biological inspiration

From a computing viewpoint, the human immune system can be considered as a parallel, distributed system that has the capacity to control a complex system over time (Farmer et al., 1986). The human immune system is composed of several layers of defence among them: physical (e.g. skin), innate and adaptive. We are specifically interested in the adaptive part of the human immune system. The adaptive system improves its response to a specific pathogen with each exposure. Therefore, the adaptive system has three key functionalities: recognition, adaptation and memory. The adaptive immune system can be divided into two major sections: humoral immune system and cellular immune system. The former acts against antigens by means of proteins called immunoglobulins or antibodies built by a specific sort of cells: B-cells. The latter, among other duties, destroys virus-infected cells. Fig. 1 illustrates the antigen recognition mechanism. An antibody *Ab* manufactured by a B-cell recognises and binds to an antigen *Ag* if *Ag* matches *Ab*'s structure. The region of antibodies which matches antigens is called the paratope. The counterpart region on antigens is called epitope. In Fig. 1 antibody Ab_1 recognise only antigen similar to antigen Ag_1.

Table 1
Antibody description.

Paratope	Agent specification	Idiotope
Precondition under which this B-agent is stimulated	Attributes, codes, data, behaviour and intern idiotypic network	References to stimulating B-agents and the degree of the stimuli (affinity)

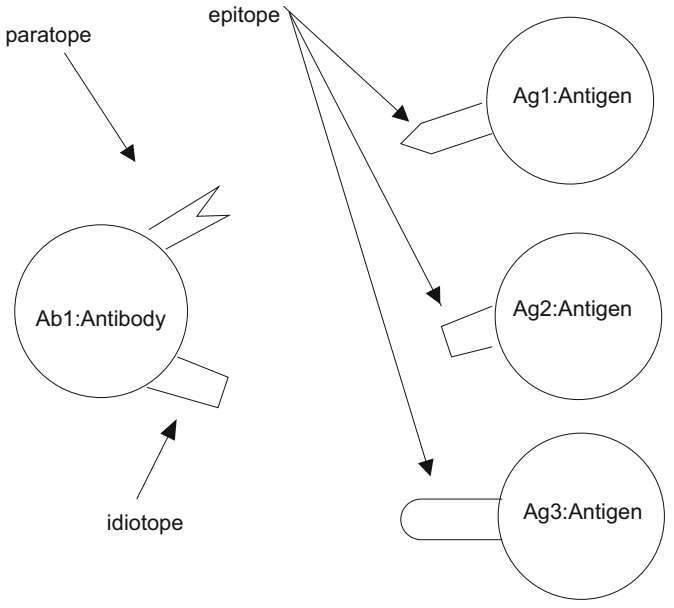

Fig. 1. Antibody and antigen recognition and binding mechanism.

The immune system continuously generates new sort of antibodies by cloning and muting existing ones. The goal is to produce antibodies that will match antigens. It is the second functionality of the immune system: adaptation. If new antigens appear the immune system may be capable of producing matching antibodies.

When an antibody match an antigen Ag_i it proliferates in order to bind to this antigen. This selection mechanism augments the concentration of effective antibodies. Even if all Ag_i antigens are destroyed, the immune system is able to keep some antibodies that could destroy them for some time. This is the third functionality of the immune system: memory. If an Ag_i antigen reappears, matching antibodies may already exist.

Among the numerous theories which try to explain the human immune system, Nobel Laureate Jerne (1974) proposed a model for immune system regulation based on communications between antibodies. These communications take the form of stimulation and inhibition. This theory is known as Jerne's Idiotypic Network. The network is defined by stimulation/inhibition links between antibodies. The region by which antibodies stimulate or inhibit other antibodies is called idiotope. These idiotopes play the roles of antigens for other antibodies. This regulation mechanism enables the immune system to maintain an effective set of cells and self-organise in order to deal with antigens.

2.2. Immune system based agent architecture

The Jerne's idiotypic network has already been used as agent architecture, for example Watanabe et al. (). This agent architecture is an interpretation of the Jerne's theory. We use the concepts developed in this reference as a basis for the approach presented in this paper. First, antibodies are represented by agents. This analogy is depicted in Fig. 1. An antibody is divided into three parts. The first part is the precondition. It states under which circumstances the antibody is stimulated. That is to say in which context this antibody may execute it's associated behaviour. This part is an analogy with the real antibody paratope which tries to match antigens epitope to recognise them. It can be seen as a perception part of the agent.

The second part specifies the behaviour of the antibody. It is the behaviour which is executed when the antibody is selected. The behaviour of the real antibody is to eliminate the antigen.

The third part is composed of references to other antibodies with degrees of stimulation (affinities). It is the idiotope part of the antibody by which it is recognised and allows interactions (stimulation/inhibition) with other antibodies.

The Jerne's Idiotypic network is defined by the different antibodies and their affinities. The affinities are either stimulation or inhibition between two antibodies. An example of idiotypic network is presented in Fig. 2. The *i*-th antibody stimulates M antibodies and inhibits N antibodies. m_{ji} and m_{ik} denote affinities between antibody *j* and *i*, and between antibody *i* and *k*, respectively. m_i is an affinity between an antigen and antibody *i*. The antibody population is represented by the concept of