Immune Mechanisms to Regulate Multi-Agents Systems

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Abstract

We present in this paper the use of immune mechanisms for the regulation of reactive multi-agents systems (MAS). More precisely, the aim of our work is to determine how computer scientists can take benefit from immune phenomenon to auto-regulate agent populations.

This regulation can be made while integrating cell and molecule behaviors into agent’s behaviors. Let us quote for example the mitosis, apoptosis or differentiation that are essential mechanisms during an immune response. The work to do or the problem to be solved are seen as foreign substances, that is antigenic bodies. The agents represent immuno-qualified cells having for goal the antigen inhibition. This process must be efficient, that means it must finish the work ($\neq$ hypo-immune response) and just the work to do ($\neq$ allergy). Each agent inherit from one or several cell behaviors. Those behaviors are extracted from immune cells which have well defined roles.

The first consists in detecting the antigen (the work to do), the second in giving alarm on a large scale, the third in increasing the capacity and the precision of the response and the fourth in eliminating the antigen. Our agents use these roles to mime an immune response.

Hereafter we explain, in three criteria, the reasons of the immune response choice for MAS.

1. The immune system is compound with autonomous entities, able to cooperate, having behaviors, receptors and means of action. Therefore, a cell is very close to the agent concept.

2. The immune system is able to divide “self” and “non-self”. Like this, it can detect the work to do among $10^{20}$ different patterns. Thus, this system is flexible and adaptative, what gets an unquestionable advantage in environments with strong variability (like for aerial images [McCoy97]). This number of possible shapes is very important, but it can be reduce for the need of simulation [SMI97]

3. The human immune system is quasi-optimal in the power of the answer to eliminate the antigen, which would allow us a quasi-optimal use of the computer resources during multi-agents processes.

The regulation of multi-agents system thanks to immunological principles is few used today [ROD98] [DAS99]. We will begin with the study of the immune concepts we use as metaphors for the regulation of the agent populations. Then, we show two examples illustrating the implementation of the immune concepts. They are dedicated to the image processing coded in levels of gray. Finally, we conclude on the interests of this immune approach for the design of MAS.

Immune Mechanisms for MAS Regulation

We approach in this section the use of a certain number of immune mechanisms for the development of self-regulated MAS.

Thus, we describe several types of immune phenomena implied into self-regulation. We see the negative and positive selections allowing to avoid the presence of cells (or agents) useless or disturbing the system. Then we see the phenomena of activation, differentiation, proliferation and programmed cellular death (apoptosis). The latter are the basis of the mechanisms for automatic regulation during an immune response. The cooperation between the T cells and the B cells within the immune system also allows a limitation of the risks of drift (under-
processing of the antigen or edge effects unexpected) while allowing an adaptation located in time and space. But we do not develop this mechanism in this paper. Finally, we propose an architecture of MAS based on the immune principles quoted above.

1.1. **Upstream regulation: negative and positive selections**

Negative and Positive selections are key mechanisms of the immune system. Thanks to these selections, the immune system is able to distinguish “self” and “non-self”.

Our approach concern the optimization of agent populations using immune regulation. That is why, we do not only see these selections as a mean of learning, but also as a regulation principle. In fact, the selections eliminate entities that useless or over active.

**Use in MAS**

More an agent is reactive, more the machine resources needed are reduced. It consists for an agent that is not well-adapted (too reactive or without reactivity), to destroy itself before it becomes active into the system. The difficulty is to determine the two thresholds of selection which are today empirically defined into our systems.

1.2. **In-process regulation: activation, differentiation (maturation), proliferation and apoptosis**

Thanks to activation, differentiation, maturation, proliferation and apoptosis mechanisms, the immune system is able to specifically increase or reduce its potential against one or several antigens. More precisely, the immune system increases the number of cells directed against an antigen during the first stage of the response and reduces it during the last stage (Figure 1).

![Figure 1: the two main stages of an immune response](image_url)

Next, we detail the different mechanisms implied into these two stages of an immune response.

1.2.1. **Activation**

The activation is the first step into an immune response. During the activation, a cell changes its morphology and its role. So, we observe structural modifications and behavioral modifications.

For example, the structural changes can improve the cell mobility, the sensitivity to chemical messengers and / or can change the life duration. The new behavior implies new aims. For instance, a macrophage having phagocitized a foreign substance becomes able to present this antigen to T4 cell.

The activation depends on the internal state of cells and on the local environment situation. Here, we restrict our activation study to the T and B cells.

A B or T cell must receive two types of signals to become activated. The first one is an antigenic signal and the second one is a proliferating signal (interleukines). There are two ways concerning the antigenic signal: a direct activation thanks to endocytosis (B cell and antigen) and a cell mediated activation (Antigen Presenting Cell and T4 cells). The direct activation is fast but can implies an over-reaction (somatic hypermutation -> allergy). The cell-mediated activation moderates the direct activation and so secures the response.
Use in MAS

For the auto-regulation, the activation is essential: only activated agents can proliferate. Inversely, an agent that received a partial activation decrease its life duration (that means the agent is no more useful or is not adapted to the problem).

To summary, we can say that there are 3 types of states for an agent:
1 – The agent is activated, so it get new properties, new behaviors and increase its life duration.
2 – The agent is incompletely activated and then it reduces its life duration.
3 – The agent is non-activated, it just waits for an hypothetic activation.

1.2.2. Differentiation - Maturation

The differentiation is implied into cell specialization. Like this, the immune system improves its efficiency against an antigen. This mechanism is linked to external signal (into the local environment of cells) or to the age of cells (maturation). The differentiation generates, like activation, structural and behavioral changes for the cells.

Use in MAS

The differentiation is generally treated by the creation of a new type of agent. In fact, the modifications justify the development of a new class of agent to improve the lisibility of the MAS. The behavior of a differentiated agent realize a qualitative evolution. It increases the agent’s efficiency to solve the problem. This augmentation has repercussions for all the system that becomes more accurate.

1.2.3. Proliferation

The proliferation increases the quantitative (number of cells) and qualitative (improvement of the affinity with the antigen) immune capacity to inhibit the antigen. This phenomenon is called mitosis.

Use in MAS

The proliferation corresponds to the creation of new agents. The new created agents are structurally and behavioraly close to their creators but not exactly the same to allow the adaptation of the system.

1.2.4. Apoptosis

The apoptosis corresponds to the programmed cellular death. This mechanism occurs when a cell is not adapted to the antigen elimination. Thus, useless cells are destroyed.

Use in MAS

The agents that are able to kill themselves take into account their internal state and the stimuli perceived by their receptors. This phenomenon essentially takes place when the activation is incomplete. The apoptosis behavior is describe by a logical circuit (Figure 2).

Figure 2: logical circuit for activation and apoptosis behaviors

General structure of our immune-oriented MAS

We can group the different mechanisms describe above into a system that reproduces a part of the immune system (Figure 3).
We apply these immune oriented MAS to image processing and more precisely to low-level image segmentation.

**Application to image segmentation**

We include into agents specialized into edge detection [BAL97a] [BAL97b] the different behaviors describe above. Like this, non-regulate agents inherits from immune cells behaviors to include self-regulation (Figure 4).

We observe the evolution of the agent population and we find again the two stages of an immune response (Figure 5). The results of the process are shown onto the Figure 6. We have tested these immune principles into an other MAS, specialized into ring detection [BAL97c]. The results of this system are shown into the Figure 7. We can compare the quality of the result obtain without any regulation and with the immune regulation (Figure 8-left). First, we observe that the success rate is very important with regulation since 10 agents as compared with the system without any regulation. Moreover, when there are too many agents without any regulation, the system becomes unstable (Figure 9). An other advantage of immune regulation is the quasi-constant process duration (Figure 8-right). This could be interesting to guarantee a process time.
Figure 5: evolution of the agent populations according to the initial number of entities

Figure 6: result of the immune-oriented MAS for image segmentation (left: original image, right: segmentation)

Figure 7: results obtained with our system (original images are 1 (otholite) and 3 (agate), segmentations are 2 and 4)

Figure 8: left: success rate according to the maximum number of agents, right: process duration according to the maximum number of agents
Conclusion

We have seen that the use of immune regulation into MAS is interesting when the number of agents is relatively importante ($>10^2$). Then, we obtain some good results for the success rate (quality of the result) and the duration of the process (time is quasi-constant). These results are very constant even for an important disparity of the agent numbers. We have compared it with the non-regulated system which is unstable and where the results are difficult to predict.

The immune-oriented MAS allows us to attenuate the number of agent influence: if this number is too little the system increases it, if not, agents use the apoptosis behavior. Like this, the system adapts itself according to its environment.

We have also shown that immune-oriented MAS permits to create image segmentation systems without any global controller nor central decisional system. The immune responses offer to computer scientists many regulation principles that can be included into MAS with few abstraction for the optimization of agent populations.

Bibliography