MULTI-AGENT COALITION FORMATION BASED ON CLONAL SELECTION

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Abstract: Coalition formation is by one of cooperative mechanisms used in multi-agent systems. Various approaches of multi-agent coalition formation ensure the coalition stability, optimal allocation of sources and payoff distribution for efficient achievement of individual or collective goals. The paper investigates mechanisms of human immune system from the coordination and cooperation point of view. It specifies requirements for effective multi-agent coalition formation on the basis of these mechanisms. The clonal selection-based algorithm is used to discover the optimal coalition structure. Finally, further directions in the research of exploitation artificial immune-based algorithms for multi-agent coalition formation are mentioned.

1 INTRODUCTION

Specific activities require a certain deal of coordination or cooperation of more artificial autonomous agents to achieve goals with minimal spend time and costs. The attention is paid to the efficient coordination and cooperation of artificial autonomous agents in multi-agent systems (MAS). The multi-agent coalition formation is one of cooperative mechanisms intensively investigated in the MAS. The paper evaluates the human biological immune system (BIS) from the coordination and cooperation points of view and specifies requirements of the effective multi-agent coalition formation based on this approach. The paper proposes the use of the immune-based algorithm ClonAlg for generating the optimal coalition structure.

2 MULTI-AGENT COALITION FORMATION

The coalition formation is a type of cooperation of artificial autonomous agents in the MAS. The coalition is a goal-oriented and short-lived group of agents solving a specific pre-defined problem. Any cooperation with artificial autonomous agents from others relevant information by software web agents is another example. The agent knowledge base can be extended by communication with others agents which provide new information to other agents. If they join together, they can cover wider search space of web documents.

Finding the optimal coalition structure is one of the problems solved in the multi-agent coalition formation. The coalition structure is a group of various coalition combinations that are able to solve a specific problem. The question is how to find such a coalition structure containing agents able to use their sources optimally. Number of coalition structures increases exponentially with the number of agents. The goal is to find efficient algorithms that are able to search solutions with minimal computational sources and time requirements. Dynamic programming, genetic algorithms or greedy algorithms are usually used for this purpose (Rahwan et al., 2009).

The problem of optimal coalition structure generation has not been sufficiently researched by the different biology-inspired approach resulting from properties and mechanisms of the human biological immune system (BIS). The BIS can offer new methods for solving problems in multi-agent coalition formation. The algorithm of the clonal selection inspired by the clonal selection principle is investigated for the finding of the optimal coalition structure.

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3 THE IMMUNE SYSTEM AND COALITION FORMATION

The BIS is a complex system that maintains the homeostasis in the living organism. It is able to recognize dangerous objects (antigens) that invoke the immune response. Antigen can be a part of the organism and risky for it (self-antigen) or can come from the outer environment, e. g. viruses, bacteria or fungi (non-self-antigen).

The BIS includes the innate and adaptive immunity. The innate immunity guards the organism. It is supported by mechanic barriers and different types of immune cells. The adaptive immunity focuses on recognition of already identified antigens. B-lymphocytes (B-ly) and T-lymphocytes (T-ly) are the main representatives of this layer. The B-ly is the main producer of antibodies and plays the role of memory cell. The T-ly eliminates dangerous antigens or regulates functions of others immune cells (Castro and Timmis, 2002).

There exist similarities between formation of immune cells into groups and the group behaviour necessary for solving complex problems of artificial autonomous agents. The immune cells are able to join and cooperatively solve a specific problem on the basis of specific stimuli. They use cellular signalling pathways that ensure transferring pieces of information from the source to the receiver. The immune cells can be perceived as pro-social biological agents that keep track of interests of the whole the BIS. Generation of antibodies, activities of complement system, phagocytosis or cytokines production are demonstrative examples of cooperation activities in case of the BIS.

The following table mentions key properties for the stability maintenance of the BIS (Dasgupta and Nino, 2008). The same attributes are specified as requirements for effective multi-agent coalition formation in this paper.

The conjunctions and similarities, displayed in the table, show the relevance for deeper research of the mutually utility of these two systems. The key question is how the concrete mechanisms of BIS can be used for discovering the optimal coalition structure. Artificial immune systems research area offers collection of immune-based algorithms that should be researched for this purpose.

Table 1: Coalition formation in the view of the BIS.

BIS attributes	Coalition requirements
Distributiveness This attribute occurs e. g. in case of lymphocytes production by the bone marrow in different places of the organism. Positive selection, negative selection, clonal selection and immune network concept are characterized by the distributiveness, too.	*Distributiveness* If the agent fails in filling the task, despite this the task should be completed. The coalition formation should not be directed by one central agent of the MAS.
Communication The BIS cells communicate directly or indirectly with the environment. Direct communication is executed mainly with the aid of adhesive molecules. Cytokines are products of immune cells activities that ensure the indirect communication in the BIS.	*Communication* Communication is direct (e. g. protocols) or indirect (stigmergy). It helps in receiving information from the environment, e. g. agents or others coalitions.
Robustness and stability Robustness and stability are expressed in cooperation of different immune cells and organs. These processes lead to the emergent property of the BIS.	*Robustness and stability* Agents should monitor their states and atmosphere in the coalition. If something is wrong, the agent signalizes it to the others. Agents should be motivated to stay in the coalition during the mission fulfilment.
Dynamics and adaptation Dynamics and adaptation are expressed in cooperation of different immune cells and organs. These processes lead to the emergent property of BIS.	*Dynamics and adaptation* The coalition of agents should behave flexibly in case of changing environment.
Learning and memory Immune cells are able to learn with the aid of feedback received from the environment and to remember already identified antigens. This ensures faster reaction of immune cells in the future. Memory is formed with the aid of immune network, gene libraries or memory cells.	*Learning and memory* Agent should be able to learn and use the learned in the future. Agent´s memory helps to react adequately to stimuli.

4 ARTIFICIAL IMMUNE SYSTEMS

Artificial immune systems (AIS) are the research subarea of computational intelligence that is inspired by the BIS behavior. In present, four groups of artificial immune system algorithms are used.

The first one stems from the diversity generation of immune cells with the aid of gene libraries

(Castro and Timmis, 2002). These libraries contain gene fragments combined for creation different immune cells. There are artificial gene libraries in AIS. These gene libraries are used for generating potential solutions changed by the mutation process towards the approximation to the optimal solution.

The second one is the group of selected algorithms – the algorithm of positive selection, algorithm of negative selection, algorithm of clonal selection and their modifications (Dasgupta and Nino, 2008), (Castro, 2006), (Castro and Timmis, 2002). The algorithms of positive and negative selection are mainly applied to classification and recognition problems. The computer security or fault detection is a typical application. The algorithm of clonal selection is used especially for classification and optimization problems (Castro and Zuben, 2000).

The third group is inspired by the immune network theory by N. K. Jerne (Jerne, 1974). This theory apprehends the BIS as a network of interconnected stimulated B-cells interacting with each other. Continuous artificial immune networks are used mainly for modeling and simulation of the BIS with the aid of differential or difference equations. Discrete artificial immune networks are based on differential equations or iterative procedures. They are used mainly for the pattern recognition, data analysis, machine learning or optimization problems.

The dendritic cell algorithm is part of the last group. It has already been used for anomalies detection in a computer network as a classifier for scanning computer ports (Greensmith, et al., 2005).

5 ClonAlg FOR COALITION FORMATION

ClonAlg is the clonal selection-based algorithm inspired by the clonal selection principle explaining the process of antibody generation. If a B-ly recognizes the antigen, clones of the same specificity are created. Mutation occurs during the cloning. It can improve the affinity (tightness of bond) between the antigen and the B-ly in the future reunion. The ClonAlg was originally designed for the pattern recognition. The optimized version of ClonAlg (ClonAlg-opt) is used for optimization tasks (de Castro and von Zuben, 2002). The ClonAlg-opt uses population of antibodies. This population pictures potential solutions of the problem (set P). The pseudo-code of the algorithm follows this procedure (de Castro, 2006):

1. Initialization: create an initial population of antibodies (P).
2. Fitness evaluation: determine the fitness of each element of P.
3. Clonal selection and expansion: select n_1 highest fitness elements of P and generate clones of these antibodies proportionally to their fitness: the higher the fitness, the higher the number of copies, and vice-versa.
4. Affinity maturation: mutate all these copies with a rate that is inversely proportional to their fitness: the higher the fitness, the smaller the mutation rate, and vice-versa. Add these mutated individuals to the population P.
5. Meta-dynamics: replace a number n_2 of low fitness individuals by (randomly generated) new ones.
6. Cycles: repeat step 2 to 5 until a certain stopping criterion is met.

The usage of the ClonAlg-opt for generating the optimal coalition structure is designed for the problem of elimination of oil spills. This problem requires the efficient, fast and optimal cooperation of sources because oil spills are spread in dynamic environment.

Three agents eliminate oil spills of two different oils in this demonstrative example. Every agent has the list of two properties relevant for elimination of oil spills. The first one describes how the agent eliminates the portion of the first type of oil spill, i. e. the usefulness of agent's sensor in the detection of the first type of oil spill. The second one describes how the agent eliminates the portion of the second type of oil spill. The coalition structure consists of different coalitions and is represented by the antibody molecule. The coalition consists of one or more agents identified by an identification value. Permutation encoding is used for the coalition representation in the coalition structure. Two restrictions have to be respected: Every oil spill has to be refined by one agent minimally and coalitions have not overlap themselves. The pseudo-code of the algorithm follows:

1. Initialization: create an initial population of N coalition structures (set P), eliminate overlapping and empty coalitions.
2. Fitness evaluation: determine the quality (fitness) of N coalition structures.
3. Clonal selection and expansion: select n_1 highest fitness coalition structures (e. g.

fitness-proportionate selection, stochastic universal sampling or tournament selection can be used) and generate clones of these ones proportionally to their fitness.

4. Affinity maturation: mutate all these copies with a rate that is inversely proportional to their fitness. Add these mutated coalition structures to the population P. The inversion operator is suitable for it. We change the position of agents of coalition and influence the quality of coalition that eliminates one particular oil spill.
5. Meta-dynamics: replace a number n_2 of low fitness coalition structures by (randomly generated) new ones.
6. Cycles: repeat step 2 to 5 until a certain final criterion is met.

6 CONCLUSIONS

The paper deals with the coalition formation of artificial autonomous agents of the MAS in the context of the BIS behavior. Key properties and mechanisms of the BIS cooperation are identified and used for the requirements specification for multi-agent coalitions.

The paper proposes to use the ClonAlg-opt algorithm for generating the optimal coalition structure. Experiments are going to be realized with the ClonAlg-opt algorithm and other clonal selection-based AIS algorithms. The immune network-based algorithms Opt-aiNet and Dopt-aiNet (Dasgupta and Nino, 2008) are going to be used for the coalition formation, too. They stem from the data clustering aiNet algorithm (Castro and Zuben, 2001) and are mainly used for the optimization purposes. Results of these experiments will be compared to the genetic algorithms. The multi-agent modeling or simulation tool will be used for experiments. NetLogo, Webots or Anylogic are suitable candidates for the above mentioned purposes.

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