Immune algorithm with Immune Network and MHC for adaptive problem solving

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ABSTRACT

Adaptive problem solving techniques such as neural networks and genetic algorithms become so popular in the AI field. The biological immune system is one of the adaptive biological systems whose functions are to identify and to eliminate foreign material.

In this paper, we propose an adaptive optimization algorithm based on immune model with immune network and Major Histocompatibility Complex (MHC). In biological immune system, immune network controls immune responses by changing its structure. The MHC is used to distinguish a "self" from other "not self". In our model, immune network is used to produce adaptive behaviors of agents, which are computing subject for problem solving. And MHC is used to induce competitive behaviors among agents. To investigate an adaptation ability of the proposed algorithm, we apply to n-th agent's travelling salesman problem called n-TSP. This algorithm performs adaptive behaviors for distributed cooperation.

1 Introduction

Such as neural networks and genetic algorithms, adaptive problem solving techniques become so popular. These techniques are based on information processing in biological organisms and are applied many kinds of optimization problems[1]. On the other hand, the biological immune system is widely recognized as one of the adaptive biological system whose functions are to identify and to eliminate foreign material. In the biological immune system, below two mechanisms are important to perform such functions. First, Immune network is used to control making antibodies to eliminate antigens by activation among immune cells. Second, Histocompatibility Complex (MHC) is used to identify foreign material by difference of MHC.

In this paper, we propose a model of immune functions and an immune algorithm as an adaptive problem solving on multi-agent system. The immune network is used to produce adaptive behaviors of agents, which are computing subject for problem solving. The MHC has behaviors list of each agent, and is used to induce competitive behaviors among agents. In our model, the entire system has two pressures for problem optimization. Each agent aims to expand own share in the problem space, and the immune network controls the performance of the aim. Furthermore, the agents compete for self-establishment in the problem with each other by difference of each MHC. By introducing such models, we construct an adaptive optimization algorithm for computer simulations. Then, we apply the proposed algorithm to n-th agent's travelling salesman problem (called n-TSP) which is one kind of multi-agent systems. Some computer simulations are designed to investigate the performance of the proposed immune algorithm.

2 Biological immune system and proposed algorithm

2.1 Immune network

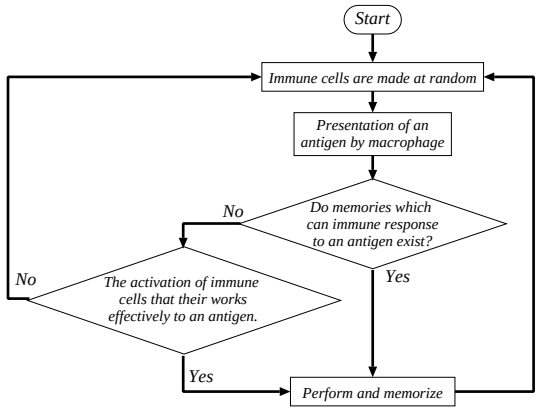


Figure 1: Memory mechanism with immune network

Immune network is defined as controlling mechanism of immune response by activation on the network. For example, if the network has applicable memory cells against an antigen, the network performs secondary immune response. Otherwise, the network performs primary immune response. The network is composed of immune cells and their connection. The immune cells are composed of following three cells.

Macrophages: Their cells are large phagocytic cells important in innate immunity, in early non-adaptive phases of host defense, as antigen-presenting cells (APC), and as effector cells in humoral and cell-mediated immunity.

T cells: Their cells, which are two main classes, are a subset of lymphocytes. One class consists mainly of cytotoxic T cells, which kill cells infected with viruses. The second class of T cells includes cells that activate other cells such as B cells and macrophages.

B cells: B cells are one of the two major classes of lymphocyte. The antigen receptor on B lymphocytes, sometimes called the B-cell receptor, is a cell-surface immunoglobulin molecule. Upon activation by antigen, B cells differentiate into cells producing antibody of the same specificity as their initial receptor.

Figure 2 is shown an example of mutual cooperation among macrophage (APC), helper T cell (Th2) and B cell. First, an antigen intrudes in macrophage, then macrophage splits the antigen into short peptides and presents of the antigen as short peptides (MHC+peptide) on the cell surface. Next, applicable T cell with TcR recognizes the MHC+peptide. In addition, the T cell helps applicable B cell that recognizes the same antigen with antibody. Finally, the B cell can produce the antibodies for the antigen.

By mutual cooperation among their cells, especially essential functions are 1) widely recognition ability by three kinds of recognition, 2) strongly adaptation ability to unknown vast antigens by production of random solutions controlling of immune response, 3) memory mechanism is used to eliminate antigens that eliminated once.

By analogy, we constructed an adaptive problem solving for the multi-agent system. The agents have (1) a sensor using macrophage with MHC, (2) a learning system using Immune Network and (3) an effector using antibody. Note that, all kinds of immune cell have only a simplest function in our design. The macrophages are used to sense environment. The T cells are used to control behaviors of an agent. The B cells are used to produce behaviors.

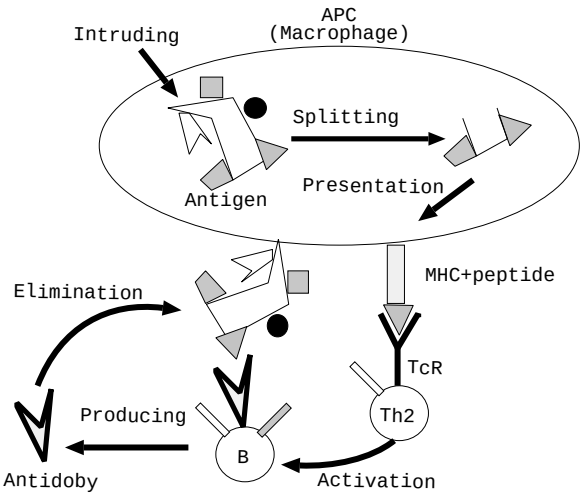


Figure 2: An example of mutual cooperation

In the multi-agent system, there is environments as dynamically changed by autonomous behavior of agents. Such problems that have too large space are hard problems for the exhaustive search. The biological immune system will have the advantages of learning and adaptive technique on the environments because the system is possible to make solutions against unknown vast problems (i.e., the problems which immune systems deal with are quite large like dynamically changing environments).

2.2 MHC

In the biological immune system, a characteristic of an individual is defined as MHC[2]. The MHC has proteins that are concerned antigen processing and host defense. If the infected MHC on the cells is different from original (uninfected) MHC, the individual can recognize antigens by matching with TcR. In other words, MHC is used to distinguish a "self" from other "not self".

For the design of effective multi-agent system, distributed operation with efficiency by interactions among agents is one of the most important aspects. It is thought as such subject that the operations which don't include repeat operation among agents design. In

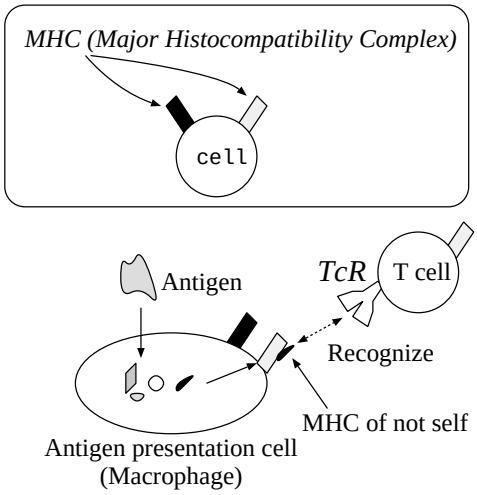


Figure 3: MHC and recognition of not self

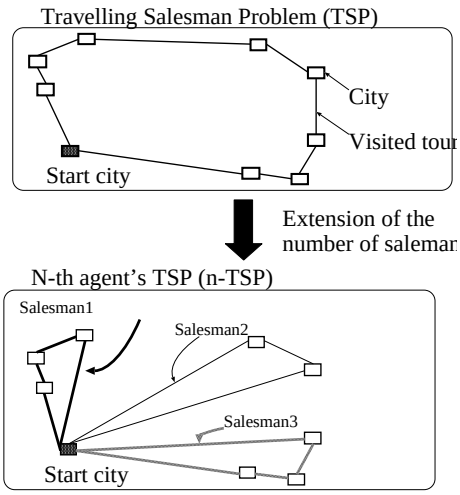


Figure 4: N-th agent's TSP

other words, we aim to construct the system whose operations of every agent compose exclusive operations. To consider the construction with biological immune system, agents own operations that are necessary information for establishment of "self" is defined as MHC, at first.

2.3 N-th agent's TSP

To investigate an adaptation ability of our model, we apply to n-th agent's Travelling Salesman Problem. Travelling salesman problem (TSP) is one of the most typical combinatorial optimization problems. The object is finding a roundtrip of minimal total length visiting each node exactly once. N-th agent's travelling salesman problem (n-TSP) is extended the definition of the number of salesman from one to the plural number. The object is finding the minimal tour by division among salesmen (figure 4). Note that, two conditions are set. First, the number of salesman is fixed while the system solves. Second, start cities whose all salesmen are corresponded.

2.4 Proposed immune algorithm

We propose an adaptive optimization algorithm on multi-agent system. This algorithm is able to search the optimal solution by using interaction between some kind of cells adaptively. We incorporate the concepts of the MHC and Immune Network into this algorithm.

We designed the immune algorithm (figure 5) to solve the n-TSP as follows.

Step 1. Definition of problem parameters such as the cities and the salesmen.
Information which agents can recognize is defined.

Step 2. Initialization of each immune cell set.
One immune cell set is composed of three kinds of immune cells called Macrophage, T cell and B cell. Each salesman agent has some immune cell sets. The initial immune cell sets make with random or memory.

Step 3. Delete and addition of immune cell set on each salesman agent.
If the immune cell set that their energies as a life-time was lost, the set is deleted. The life-time of immune cell set is increased by interaction of each cell in the set and is decreased with time. If one immune cell set is deleted from salesman agent, new immune cell set is created at random and added.

Step 4. Selection of next cities by salesman agent.
Macrophages of each immune cell set determine own value at random. This value is the city number that the salesman agent should visit next time. T cell and B cell have only one candidate city number that the salesman agent should visit next time. The three immune cells of one immune cell set check whether own value agrees each other or not. If their values agree, their three immune cells interact and the city that the salesman agent should visit is selected. However, if the city that this salesman agent should visit has been visited by other sales-

man agent, 1) each salesman agent compares with their costs that is calculated by using MHC, then 2) the salesman agent whose the cost is lower can visit the city. At this point, MHC is list of city number that the salesman agent visited, and its initial state is empty.
Back to step 3.

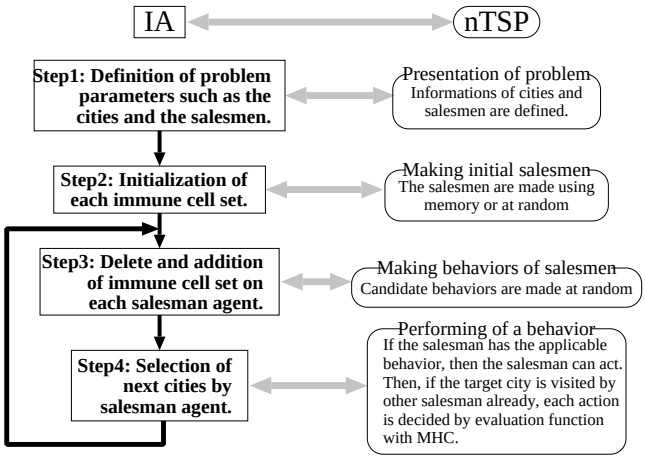


Figure 5: Proposed IA and n-TSP

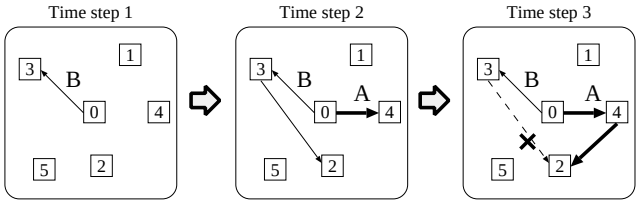
2.5 Behavior of the proposed IA in n-TSP

In our model, one salesman of n-TSP is equal to one agent of multi-agent system. In figure 6, the table (a) is shown states of each immune cell and MHC of each salesman, and figure (b) is shown the tour of each salesman each time step. In this example, each salesman is composed of 1 Macrophage, 3 T cells, 3 B cells and MHC as a tour. The system behaves as follows. First, Macrophage acquires city number at random and present to T cell and B cell. Second, if T cell recognizes this number, the T cell try to help B cell. Third, if T cell and B cell recognize the same number, the B cell produces an antibody and travels. Then, MHC is changed. Note that, in the third time step, salesman A tries to perform B cell, but second city is visited by salesman B. By using the evaluation function (equation 1), it is decided that salesman A has a better tour than salesman B. Therefore, salesman A visits second city and changes MHC. In addition, salesman B removes second city from MHC.

(a) An example of behavior list of the proposed system

	Saleman A				Saleman B			
Time step	M	T	B	MHC	M	T	B	MHC
0		2, 4, 5	1, 2, 4	0		1, 2, 3	2, 3, 4	0
1	1	2, 4, 5	1, 2, 4	0	3	1, 2, ***3***	2, ***3***, 4	0, ***3***
2	4	2, ***4***, 5	1, 2, ***4***	0, ***4***	2	1, ***2***, 3	***2*** 3, 4	0, 3, ***2***
3	2	***2***, 4, 3	1, ***2***, 4	0, 4, ***2***	5	2, 3, 4	1, 2, 3	0, 3

M: Macrophage
T : T cell
B : B cell



(b) Behavior of salesmen

Figure 6: An example of behavior of proposed IA in n-TSP

3 Experiment

3.1 Design of IA for n-TSP

The design of antigens and immune cells are as follows.

[Antigen] : Information of "cities" and "salesmen".

- cities;
  - m; the number of cities.
  - $Pos(m)$; position of cities.
  - $Dis(m_i, m_j)$; distance between m_i and m_j.
- salesmen;
  - n; the number of salesmen.
  - Now_Town; the city which it is in at this present.
  - $MHC[\,] = Traveled_Town[1...m]$; list of city number that the salesman agent visited, and its initial state is empty.
  - $Cost(Traveled_Town[\,]) = \sum_i^m Dis(i, i+1)$; cost of traveled tour.
  - $Strength = 1/Cost()$; easiness to spread the tour.

where MHC is used to compare the *evaluation value* of which both salesman agent would like to visit the same city at once. Then, the salesman agent that has lower value can visit the target city. The *evaluation value* is formularized as follows.

$$Eval(m_{action}) = Dis(Now_Town, m_{action}) * Strength \quad (1)$$

The *evaluation value* becomes so low value that the cost of the tour is long. Therefore, the tour whose cost is smaller is supposed to be designed by the equation.

[Macrophage] : Selection of the city number that the salesman agent should visit next time.
Composed of Traveled_Town[ ] , "Local_View[ ]" and "Energy".

- $Local_View[1...m]$; information of partial cities.
- $Energy$; life-time.

where $Local_View[\,]$ is defined as the target city number, and is decided at random. Note that, to visit the target city needs applicable T cells and B cells (i.e. mutual cooperation. see figure 2).

[T cell] : Helping activation of B cell.
Composed of Local_View[ ] and Energy.
Only when the $Local_View[\,]$ between Macrophages and T cells match, the T cell can help activation of B cell (i.e. step 4 in the algorithm).

[B cell] : Making antibodies.
Composed of "m_{action}" , Local_View[ ] and Energy.

- m_{action}; visit city next off.

When one B cell that was helped by T cell makes an antibody as a behavior.

[Antibody] : Perform behavior of agent.
Composed of m_{action}.

3.2 Definition of experiment

The problem defined in the figure 7 and table 1. The parameters of proposed IA are set in figure 2. The arrangement of the cities is a circle, which a start city was moved to the center, and the circumferential cities are being arranged uniformly. The performance is confirmed in this experiment with two standards. First is a visited all cities, and second is the cost proceed in the optimization direction.

Table 1: Parameters of n-TSP

the number of cities	13
the number of salesmen	3
terminal condition	1000 time steps

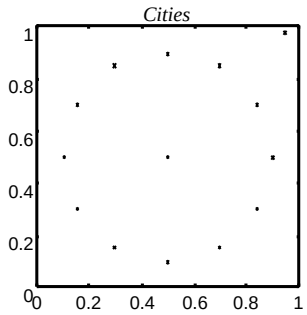


Figure 7: The arrangement of the cities

Table 2: Parameters of proposed IA

the number of Macrophages	1
the number of T cells	5
the number of B cells	40
initial energy	1.0
threshold	2.0
decrease of energy	0.1

3.3 Results and discussions

In the figure 8, *Cost* is the evaluation of the tour and *Complete* is the degree that satisfies the condition of the solution as n-TSP ($0 < value \leq 1$, if the value is 1, the tour composed all cities and no overlap). Though the production of solutions is made by random, the decrease of the cost by communication used MHC (equation 1). However, the algorithm could not find the optimum solution yet (figure 9). As a reason, the behavior that a salesman agent performed is memorized, then the behavior is often fixed without estimation of whether the behavior is good or bad. Therefore, this algorithm may be necessary to shift of search scope from the fixed point because the decrease of the cost isn't seen after 500-time step.

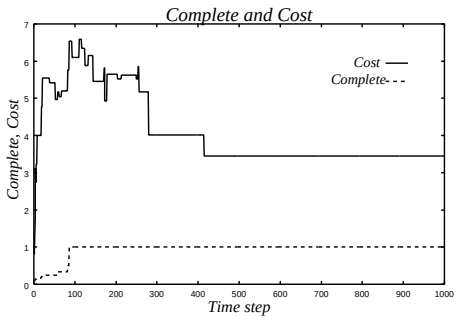


Figure 8: Transition of cost

Figure 10 is shown difference of behaviors between

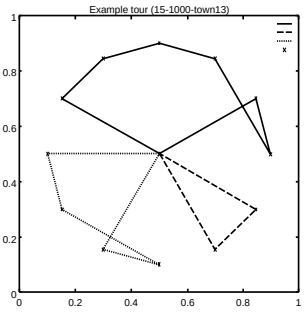


Figure 9: The tour in the last step

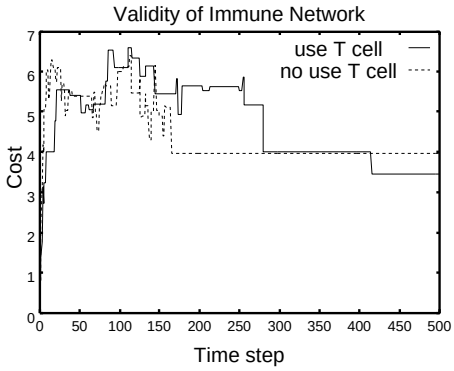


Figure 10: Comparing the cost of using T cell and no using T cell

using T cell and no using T cell. In our model, T cell and B cell recognize the same number. To confirm the effect of the T cell, we compared the cost of using T cell and no using T cell. In no using T cell, the decrease of cost is early because matching condition disappears, but the cost is fixed early point. It is considered that recognition by T cell functions as a pressure for leading to optimum solution.

In the view point of autonomous distributed systems, to operate multi-agent system appropriately is important to decide 1) cooperation or competition among agents and 2) division of work domain (own share). In proposed model, the opponents for interactions deal with "not self" that intrude into "self". And agent's own share is constructed with trial and error by competitions among the opponents. In addition, the share is possible to renewal by appropriately changing the own network. However, our model has some points which should be improved as follows. The characteristics of the entire problem is ungraspable because presenting problem by macrophage only one city at a time. And it is unable to produce better behaviors from the finding memories. Furthermore, self-definition is variable, but it is fixed in biological immune system. Therefore, the definition should need to examine about the validity.

In biological immune system, the features extraction of the problem (figure 2)is possible. The features extraction is also important to distinguish "self" from other "not self". Accordingly, we need to examine about the presenting and the processing of problem as future works.

4 Conclusion

We proposed a model of immune functions and an immune algorithm as an adaptive problem solving on multi-agent system. Each agent aims to expand own share in the problem space, and the immune network controls the performance of the aim. Furthermore, the agents compete for self-establishment in the problem with each other by difference of each MHC. This algorithm was applied to simple n-TSP, and validity was examined. we need to examine about the presenting and the processing of problem as future works.

Acknowledgements

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REFERENCES

[1] Thomas Back (editor): "Proceedings of The Seventh International Conference on Genetic Algorithms, Morgan Kaufmann", 1997.

[2] Charles A. Janeway, Jr / Paul Travers / Simon Hunt / Mark Walport : "Immunobiology : The Immune System in Health And Disease",1997.

[3] Y. Ishida, H. Hirayama, H. Fujita, A. Ishiguro, K. Mori.: "Immunity-Based Systems and Its Applications", CORONA, 1998

[4] D.E. Goldberg,: "Genetic algorithm, search optimization and machine learning", Addison Wesley, 1989.

[5] K. Mori, M. Tsukiyama, T, Fukuda.: "Application of an immune algorithm to multi-optimization problems",T. IEE Japan, Vol.117-C, No.5, pp.593-598,1997.

[6] S. Forrest, A.A. Perelson.: "Genetic algorithm and the Immune system", Proc. of 1st Workshop on PPSN, pp.320-325,1990.