A PROPOSAL AND EVALUATION OF AN EXTENDED IMMUNE OPTIMIZATION ALGORITHMUSING THE IMMUNE CO-EVOLUTIONARY PHENOMENON AND THE CELL-COOPERATIONFOR THE DIVISION-OF-LABOR PROBLEMS

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ABSTRACT
The purposes of this paper are to propose and evaluate an immune optimization algorithm inspired by a biological immune cell-cooperation and co-evolutionary phenomenon. And this algorithm solves the division-of-labor problems in multi-agent system (MAS) through the interactions based on such immune functions. The co-evolutionary models searches the solution through the interactions between two kinds of agents, one of the agent is called immune agents which optimize the cost of its own work. The other is called antigen agents which realize the equal work assignment. According to the interactions, our method searches a minimum-costed solution which maintained the even division among the immune agents. There are three kind of interactions in our algorithm, division-and-integration processing is used for optimization of the work-cost of immune agents and, escape processing is used to perform equal work assignment as a result of evolving the antigen agents. To investigate the validity, this algorithm is applied to ``*N*-th agent's Travelling Salesmen Problem'' as a typical problem of MAS. The good property on solving for MAS will be clarified by some simulations.

1 INTRODUCTION

Adaptive problem solving techniques, such as neural networks and genetic algorithms, are based on information processing in biological organisms and are applied on many kinds of optimization problems. A biological immune system is one of the adaptive systems and the studies are making advances [Bersini 1991, Farmer 1986, Forrest 1990, Ishida 1996]. The biological immune system is widely recognized as one of the adaptive biological system whose functions are to identify and to eliminate foreign materials.

In this paper, we propose and evaluate an immune optimization algorithm inspired by biological immune cell-cooperation, and this algorithm solves the division-of-labor problems in multi-agent system (MAS). For the following reason, it is very useful to solve these problems for application. As the reason, we need to correspond to problem space size that becomes more complicated in recent years. MAS is a study in the field of distributed artificial intelligence and attracts attention as a framework for solving effectively using cooperations or competitions through interactions. Therefore, it is very meaningful to examine the application to MAS.

The proposed algorithm solves the problem through interactions between agents (called `immune agents'), and between agents and environment (called `antigen agents'). This method for implementation of the interactions uses division-and-integration processing inspired by immune cell-cooperation. There are three functions in our algorithm: division-and-integration processing and escape processing. The division-and-integration processing optimizes the work domain through the interactions between immune agents, and the escape processing performs equal divisions through the interactions between immune agents and antigen agents. Then, in order to investigate the validity of the proposed method, this algorithm is applied to ``*N*-th agent's Travelling Salesmen Problem (called *n*-TSP)" as a typical problem of multi-agent system. The good property on solving for MAS will be clarified by some simulations.

2 ANALOGY FROM BIOLOGICAL IMMUNE SYSTEM

In the point of view of engineering system, it is considered the immune cell-cooperation to be a parallel distributed system with role differentiation. The roles in this system are (1) fragmentation and presentation of antigens, (2) activation of producing specific antibodies, (3) elimination of the antigens by specific antibodies, and (4) control of the functions. We have as object to model, implement and apply to MAS. We construct an optimization algorithm based on a concept that (1) fragments a problem, (2) solves the fragmented sub-problems by the specific sub-solutions, and then (3) solves whole the problem through combination of these sub-solutions. We call these procedures division-and-integration processing.

In addition, we introduce a co-evolutionary concept that the immune system evolves against the virus which evolves so as to escape the elimination of the system (see figure 1). We call the procedure which attempts to survive antigen itself by counter-checking, escape processing. In order to apply this concept as a searching method in MAS, we construct a procedure liken the escaping virus to changing environments.

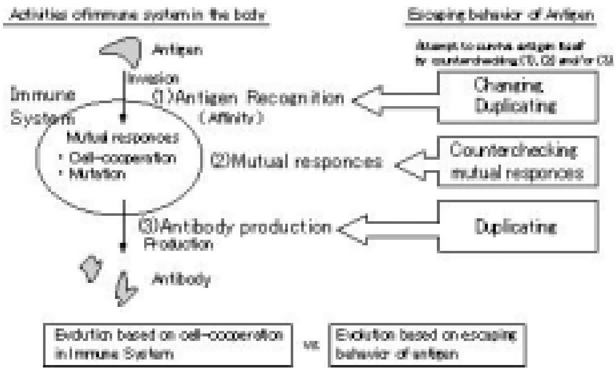


Figure1. Concept of immune co-evolutionary phenomenon.

3 ISSUES OF DIVISION-OF-LABOR PROBLEMS

The key subject of division-of-labor problems is to focus on the issues of distribution of works for agents. The solvers of the problems are defined as follows: the domain that each agent covers is defined as work domains (*WD*), and the aggregate total of the work domains is defined as problem domain (*PD*).

There are two aims in the division-of-labor problems. They are: (a) each WD_i that is assigned by agenti must be divided evenly and, (b) the system performs effective division-of-labor by optimizing each WD_i. As a typical case problem of the division-of-labor, we deal with *n*-TSP to investigate an adaptation ability of our model. The objective is finding the minimal tour by division among salesman. Note that one condition that all salesmen use the same city as the starting point was set in our experiments.

4 PROPOSED METHOD

The algorithm solves the problems through two searching ways, (1) division-and-integration processing by salesman agents and (2) escape processing by city agents in the environment. The procedures of the proposed algorithm against an *n*-TSP are described as below (see figure 4).

[Step1. Definition of problems and immune functions.]

Cities and Salesmen as the problem must be defined. Salesman's unique ID and division-and-integration processing for tours of each salesman must be defined. At this point, each city has the ID for expression of salesman visiting the city.

[Step2. Calculation of objective function.]

The cost of salesman is calculated by following function.

$$Cost(S_i) = \sum distance(tour_{S_i}) \qquad (1)$$

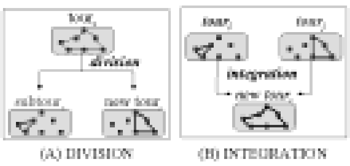
- S_i: Salesman *i*.
- $tour_{S_i}$: the tour of Salesman *i*.

[Step3. *division processing* with Simulated Annealing.]

One salesman tries to divide own tour into two subtours for searching lower costs according to these steps (see also figure 2-(A)): decide of any one $subtour_j$, make new $tour_i$ except the $subtour_j$, calculate costs of both tours and then, if the cost is improved, the division will be performed (as a consequence, a new agent is generated).

[Step4. *integration processing*.]

Two salesmen try to integrate the tours for searching lower costs by following steps (see also figure 2-(B)): decide of any two tours, make new tour by binding, calculate cost of the new tour and then, if the cost is improved, the integration performed (as a consequence, a original salesman is deleted).



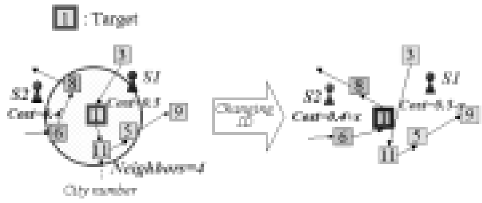


Figure 2: Examples of Division and Integration. Figure 3: Escape processing

[Step5. Mutation.]

Swap any two cities. If the cost, after swap, is improved, the swap will be performed.

[Step6. Calculation of objective function.]

The city agent's cost (same as a cost of visited salesman) is calculated by the function (1).

[Step7. Escape processing.]

This approach changes ID of a city depending on neighbors cost to process following steps (see also figure 3). First, check costs of salesmen that visited neighbor cities of target city. Second, if the other salesman's cost lower than its cost, the city changes its ID into the other. As a consequence, in this example figure 3, the ID of target city is changed to *S2*, and then, the target city is visited by *S2* like the right side of figure 3.

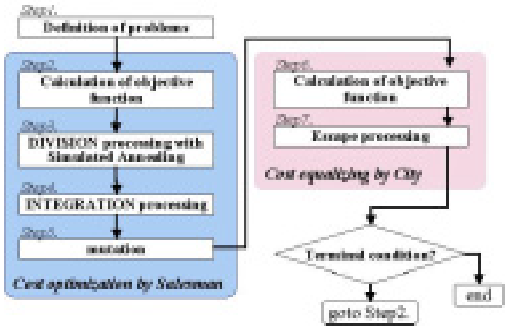


Figure 4: Flowchart of proposed method.

5 EXPERIMENT

5.1 Problem definition

In order to evaluate the performance of our method, we apply this algorithm to the following *n*-TSP. One of the reason to adopt the *n*-TSP is that *n*-TSP provides two peaks deceptive problem. In this deceptive problem, each city is arranged on two-fold concentric circles. Two kinds of problems can be made by changing two circular radius ratios. As for one problem, c-type is the answer whose tours visit other circle's cities after the one circumferential's ones. O-type is the answer whose tours visit each circumferential's city alternatively. Definition of problem is set in table 1.

5.2 Results and discussions:

We applied the four method to the problem defined table 1: (1) Genetic Algorithm using subtour crossover (population = 400, terminal generation = 10,000), (2) Saving method, (3) Saving-GA (population = 100, terminal generation = 5,000), and (4) our proposed method (neighbouring cities = 4, initial salesmen = 48, terminal steps = 1,000). In subtour crossover, two subtours which have the same elements are looked up, and those subtours are replaced. It becomes possible that the destruction of the important subtour is prevented by adopting this method [Yamamura 1992]. Saving method is a kind of deterministic approximate method which is a famous method in the filed of vehicle routing problem in the front of very fast algorithm. Saving-GA is a hybrid method [Yokoyama 2001] that GA searches by using the result of saving method (and this GA uses the subtour-crossover also). Note that, in our computer simulations, the Saving-GA doesn't use the improving by simulated annealing because it takes excessive run time in accordance with the authors saying in the paper. It is important that a high quality solution with divided cost evenly among agents finds fast in the best way possible.

Table 1: Definiton of problem.

The number of cities	49
The number of salesmen	3
The arrange ment of cities	Dual circle
Start city	Center of circle
Radius (out, in) Case1 (O-type) Case2 (C-type)	 Out=0.5, In=0.384 Out=0.5, In=0.386

Figure 5 shows the obtained solutions (*Tour* and *Cost*), the run time for obtaining the solutions, and the degree of division (*sum error*: calculated by equation 2).

$$sum\_error = \sum_i^N \left| \overline{\cos t} - x_i \right| \qquad (2)$$

$$\overline{\cos t} = \left(\sum_i^N x_i\right) / N \qquad (3)$$

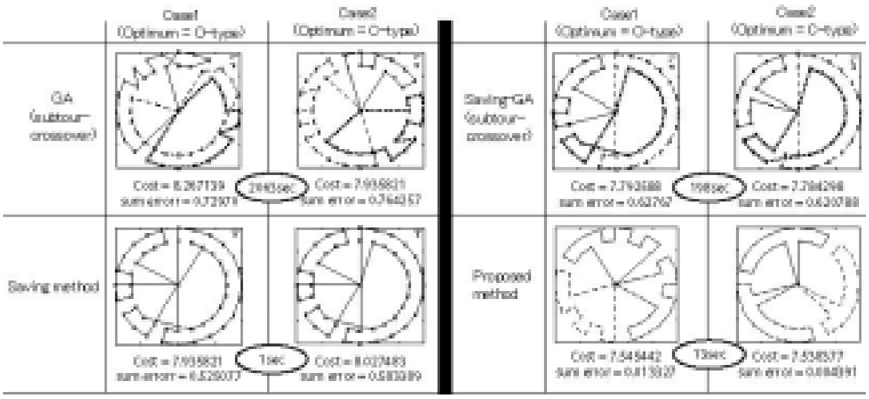


Figure 5: Results.

The solutions obtained by GA and saving method are 5-10% poor costs in relation to best solution, thus these methods are no sufficient abirity from point of view's optimization for whole working's cost. And these sum error have differences more than 20% among salesmen's cost, so the dividing ability is insufficiently lso.

On the other hand, saving method is possible to obtain a good quality solution with short run time. In the dual circled *n*-TSP which is a kind of deceptive problem, however, there is a deceptive case which the saving method obtain the same or similar solution although the problems are different. In fact, the dual circled problems has two typically solutions: c-type and o-type, but the saving method couldn't obtain the o-type's one. Therefore, the saving-GA which uses the solution of saving method as initial population is possible to obtain better (lower cost) solution with short run time than GA, but it converges to the c-type solution even though the type of problem is o-type.

The proposed method is possible to get a good solution in a short time extremely comparison with GA and Saving-GA, althgouth it needs more run time against the saving method. The solutions which are very lower costs (proposed method's cost is lowest!), in addition, the *sum error* has little difference (only 1-2% among selesmen's cost) also. According from these results, it is considered that our method is very efficient algorithm for division-of-labor optimization.

5 CONCLUSIONS

In this paper, we proposed and evaluated an immune optimization algorithms in order to verify the engineering application possibility of artificial immune system Our method solves the problems through combination of division, integration and co-evolutionary approach. These functions are based on local interactions between agents, and between agents and environment. In MAS, clarifying the objective function considered all agents and components in the environment is too hard problem, and then it is important optimizing of the whole problem by using the local interactions. Since our algorithm can optimize division-of-labor problems, it can expect what is functioned effectively as an optimization algorithm in MAS.

Te first author acknowledges the Grant-in-Aid for Scientific Research (Grant-in-Aid for JSPS Fellows).

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