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Application of path planning algorithm by slime molds

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Abstract—This paper proposes an Artificial Plasmodium Algorithm (APA) mimicked a contraction wave of a plasmodium of physarum polucephalum. Plasmodia can live using the contracion wave in their body to communicate to others and transport a nutriments. In the APA, each plasmodium has two information as the wave information: the direction and food index. We apply APA to a maze solving and route planning of road map.

1. Introduction

Of late years, many algorithms which mimicked various creatures have proposed. Major examples are follows: Particle Swarm Optimization (PSO) [1]: based on the swarm behavior such as fish and bird schooling in nature, and Bees Algorithm (BA) [2][3]: based on the food foraging behavior of swarms of honey bees. They can perform smart in the nature making full use of their memory and own ability although they are small.

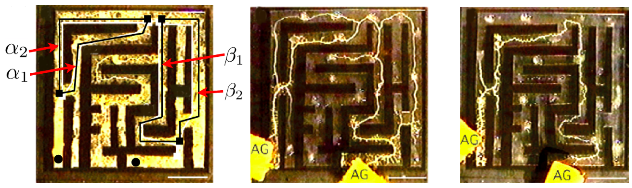
By the way, the creature, which we focus on in this study is the plasmodium of Physarum polucephalum. This plasmodium is multinuclear and unicellular organism, and it does not have any differentiated organ. Thereby, the plasmodium senses environment, decides and moves using the whole body. When the plasmodium is cultivated, their body is getting bigger like $5m^2$. However, no matter how big their body become, they can behave like in a body in spite of unicellular organism. In addition, the results that this highly homogenized plasmodium can solve the maze and find the shortest path were reported [4][5][6]. This is indeed true and was experimentally proved.

In this study, we consider about how the plasmodium solves the maze and find a shortest path. Furthermore, based on our consideration, we propose a new algorithm modeled on the plasmodium, called "Artificial Plasmodium Algorithm (APA)", and confirm its an effectiveness.

2. Plasmodium in nature

2.1. Behavior of Plasmodium

Plasmodium is a large unicellular organism with a lot of nucleuses and network of flowing protoplasm. Plasmodium can move to flow the protoplasm as its direction switches back and forth periodically known as shuttle streaming. Small components of the flowing tube are very densely connected at the frontal part and there are reticulate tubular structure at the rear part when the plasmodium explores a food. This reticulate tube plays an important role in intracellular transport of material, since it becomes a pathways of shuttle streaming. The shuttle streaming includes the information of direction when the tube structure developed. In other words, the tube structure develops and grows along a *contraction wave*. Thus, the plasmodium is gathered at comfortable place (i.e. nutriment, warmth and humidity) or escape from harsh conditions (i.e. coldness and drying).



(a) (b) (c)

Figure 1: Process of the plasmodial maze-solving[4]. (a) Initial state. (b) Intermediate state. (c) Final state.

2.2. Application of real physarum polycephalum to solve a maze

It had been reported that the true plasmodium of physarum polycephalum can solve and find the shortest path in a maze by T. Nakagaki et. al. [4][5][6][7]. The process of true experimentation shown in Fig. 1.

Plasmodia propagate from original sites along pathways, avoiding walls, and they merge into a single cell (a). After two pieces of nutrients are placed as a start and exit point in the maze, the network of pronounced tube is approximated (b). Protoplasmic tubes are connected all the path between two points and only the shortest path are remained gradually with time progress (c).

3. Artificial Plasmodium Algorithm (APA)

We propose an artificial plasmodium algorithm (APA) mimicked the contraction wave of the true plasmodium.

The contraction wave is part of the shuttle streaming and it has the information of propagation direction. The wave sources are frontal part of the plasmodium and any food sources. When there are two food sources, the contraction wave propagates between two sources, and it is switched from one food source to another every several waves.

In our algorithm, the search space is defined as a maze which divided into discrete space of arbitrary size of $x \times y$ cells. The maze is composed of pathways and walls. Plasmodia can propagate and exist on such pathways. Each cell has a propagation direction to neighbors which are located on the four points of the compass: north, south, east and west. During process of the contraction wave, the contraction wave transmits transport direction to each cell from frontal part or food sources. After the wave, each cell has and knows the direction to the destination. In order to find the path, they trace their own direction. Four processes to find a path are follows.

1. Initialization.
2. Placement of two foods in the maze.
3. Spread of contraction waves.
4. Search for the path.

3.1. Initialization

In the initial state of APA, all the pathways of the maze are covered by plasmodia, namely, M plasmodia exist in the maze.

3.2. Placement of two foods in the maze

We put two food sources as the start and the exit points on the pathways of the maze. The food sources are distinguished that respective food sources have a food index like food “1” and “2”.

3.3. Spread of contraction waves

A contraction wave starts to spread between two food sources to find a path. The example is shown in Fig. 3(a)–(d). Each plasmodium i ($i = 1, 2, \cdots, M$) has two information: a direction and the food index. We call these two information “wave information”, and they are decided by the contraction wave. The direction comes in 4 types (north, south, east and west) and it denotes which neighbor the contraction wave came from. Note that decision of the direction by the contraction wave is once. Moreover, the food index comes in 2 types, and it denotes which food source the contraction wave came from. For example, the wave from food “1” has the food index “1”.

First, the contraction wave spreads into circumference of the two food sources. This is to say, the four plasmodia in the neighborhood of each food source have the food index and the direction of each food source (as shown in Fig. 3(a)).

Then, the plasmodium i, which have no wave information, is chosen randomly. When one or more plasmodia, which have the wave information exist in the neighborhood of i, the plasmodium i obtains the food index and the direction. The food index of i is copy of that of the neighbor, and the direction information of i is a direction of the neighbor viewed from i. We repeat these process. In this way, the contraction wave gradually spreads into all the plasmodia.

When all the plasmodia have the wave information, the contraction wave stops propagating.

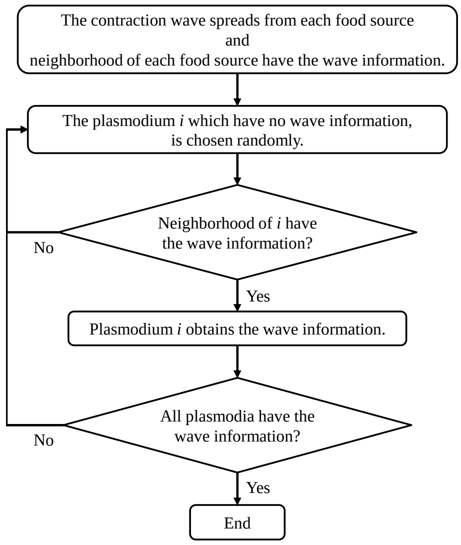


Figure 2: Flowchart of spread of the contraction waves

3.4. Search for the path

After the contraction wave finishes propagating, two plasmodia are chosen randomly with fulfilled following rules:

1. Two plasmodia have different food indexes, respectively.
2. Two plasmodia are located in the neighborhood of each other.

In Fig. 3(c), two plasmodia with ellipse shape are possible candidacy. After two plasmodia are chosen, the two plasmodia become a way point between two food sources and pursue the each direction to food sources as a path, with using the direction information obtained by Sec. 3.3 shown in Fig. 3(d).

4. Computer simulations

We simulate APA in comparison to Breadth-first Search and Best-first Search which are graph and tree search algorithms. Both algorithms start at the some arbitrary node of a graph. Breath-first Search explores the all neighbor nodes first, before moving to the next level neighbors. In contrast, Best-first Search explores the most promising node n decided by an evaluation function $f(n)$. In this study, we use

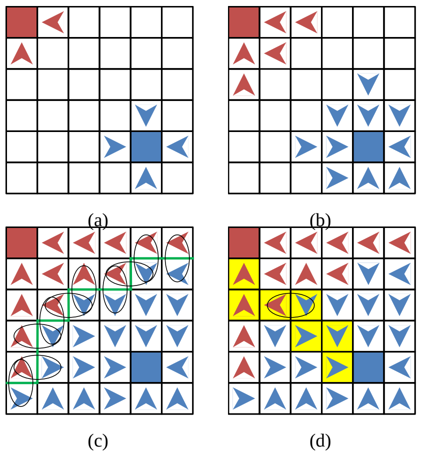


Figure 3: The extraction of process of the contraction wave in APA. (a) The contraction wave spreads from two food sources, then the neighborhood of each food source have the wave information. (b) The contraction wave gradually spreads into all the plasmodia. (c) Two plasmodia are chosen randomly. (d) The path is appeared pursuing the each direction from the two chosen plasmodia.

a Manhattan distance D between a node n and a goal as an evaluation function decided by

$$D(\mathrm{x},\mathrm{y}) = \sum_{k=1}^{n} |x_k - y_k|, \qquad (1)$$

where $\mathrm{x} = (x_1, x_2, \cdots, x_n)$ and $\mathrm{y} = (y_1, y_2, \cdots, y_n)$.

4.1. Simulation in the maze

We use the maze which is as same as used in previous research [4][5][6][7] shown in Fig. 4. The maze is set as 16 cells length × 16 cells width and composed pathways ($Passage\ width = 1$) and walls. Red circles in the maze indicate the start and exit point. We note that the maze has 4 possible routes between the start and exit: the shortest path is route $\alpha_1 + \beta_1$ and $\alpha_2 + \beta_1$. A route $\alpha_1 + \beta_2$ and $\alpha_2 + \beta_2$ are longer approximately 1.04 times.

Simulation results of 100 trials are shown in Table 1. We can see that APA found all possible routes including the shortest path with high percentages although Breath-first and Best-first found only the shortest path. This is because the contraction wave and its update of APA are depending on randomly, thus the path is changed every each time. This results indicate that APA can find multiple solutions in addition to optimal solutions.

4.2. Application to navigation of road map

We now apply APA to road navigation [8]. Figure 5(a) shows the network of US interstate highways. In this case, we suppose that we are planning car trip from Houston to Seattle using interstate highways. Each city is connected to

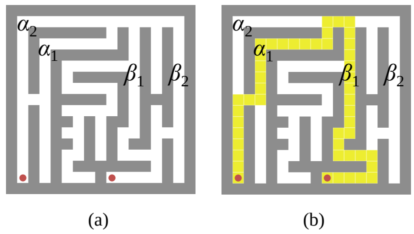


Figure 4: (a) Maze used in the simulations.Two red circles indicate the start and the exit points, respectively. (b) The shortest path is indicated as yellow color in the maze.

Table 1: Simulation results

	Breath-first	Best-first	APA
$\alpha_1 + \beta_1$	49%	50%	36%
$\alpha_2 + \beta_1$	51%	50%	34%
$\alpha_1 + \beta_2$	0%	0%	17%
$\alpha_2 + \beta_2$	0%	0%	13%

others by highway networks, many possible routes between 2 points are considered.

In order to confirm an effectiveness of APA, we also simulate by using Breath-first search and Best-first search algorithm. The shortest routes is shown in Fig. 5(c), the simulation results are shown in Fig. 5(b), Fig. 6 and Table 2. Breath-first search found only one route which is the shortest. Best-first search found the shortest route by 3%, and also other routes which are within 10% of difference of distance from the shortest route are 31%. On the other hand, APA found the shortest route by 47%, and all of found routes are within 10% of difference of distance from the shortest route. This is to say, if we are informed that somewhere of the shortest route is unavailable because of an accident, APA can find approximately short route than other search algorithms.

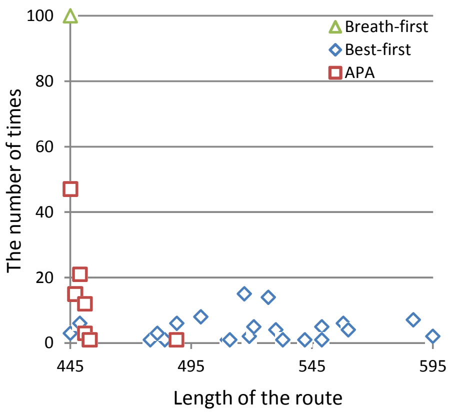
5. Conclusions

We have proposed artificial plasmodium algorithm (APA) mimicked the contraction wave of the plasmodium of physarum polucephalum. In APA, each plasmodium has two information as the wave information: the direction and food index. The contraction wave spreads from the two food sources and when the plasmodium received the contraction wave, the plasomodium can know the direction of either food source. After the contraction wave finishes propagating, two plasomodiums are chosen randomly and pursued each direction to the food sources as a path.

We have applied APA to the maze solving and route planning of road map. From these results, we can say that the proposed APA found the optimal route in any cases. In addition, the found routes are not only the shortest path but also approximately short routes with high percentages.

(a) (b) (c)

Figure 5: (a) The network of US interstate highway is indicated by the orange lines. The start point (Houston) and the goal (Seattle) are indicated by black and white stars, respectively. (b) All conceivable routes which are obtained by APA. There are not only the shortest path, but also a near routes. (c) The shortest path.



(a)

Figure 6: Scatter graph of the simulation.

Table 2: Simulation results

	Breath-first	Best-first	APA
Average	445	518	447.56
Standard deviation	0	41.27	14.10
Minimum	445	445	445
Maximum	445	595	489

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