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Two-dimensional cellular automata model of microorganism morphosis

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Abstract: Living organism creates various shapes of the organ and the body by lamination of cells. An understanding of the generalized mechanism of biological morphosis is considered fundamental to applications in various fields, such as the mass-production of molecular machines in nanotechnology and artificial synthetics in biology. This study developed the model to simulate the morphogenetic mechanism of cells under the condition of two-dimensional cellular automata. Each cell is renewed by transition rules and the state of the next step was decided by the state of the cell and that of neighboring sites. The microbes such as protists create a variety of shapes by a single cell or a few cells. As trial simulation cases, we simulated the shape similar to various form of the microbe. Using our model, we confirmed that the variety of shapes was emerged with the slight changes of some parameters value..

Keywords: cellular automaton, self-organization, unicellular organism, morphosis

1 INTRODUCTION

Living organism creates various shapes of an organ and the body by lamination of cells. An understanding of the generalized mechanism of biological morphosis is considered fundamental to applications in various fields, such as the mass-production of molecular machines in nanotechnology and artificial synthetics in biology (synthetic biology). Furthermore, it is difficult to construct large, complex machine systems that exceed a certain size, using a top-down approach. Therefore, such complex machine systems must be constructed using a bottom-up approach based on the phenomenon of biological morphosis.

Historically, researchers have attempted to develop a mathematical model to simulate the morphosis of living matter. Studies on the reproductive models of a body surface design, namely, the Turing model (Turing, 1952), and those on the leaf vein pattern of a plant (Feugier, 2005) and mollusk shell patterns (Meinhardt, 2003) are examples of previous research. In addition, many researchers have used a cellular automaton model to study tissue or tumor growth. Although these models can simulate a number of features of biological morphosis on a computer, they cannot reproduce the entire body on the basis of unified equations and rules, such as cytodifferentiation by gene expression → morphosis of cells → organogenesis → emergence of function.

2 OBJECTIVE

This study developed the model to simulate the morphogenetic mechanism of cells under the condition of two-dimensional cellular automata. Each cell of the automaton model expresses cell organelle and holds an various states in each cell. We modeled the mechanism of gene expression by the information exchange between the adjacent cells of the automaton model. Furthermore, shapes emergence of various creature organs was simulated by the rules of cellular differentiation and rules of hierarchical formation of cells. Simultaneously we also simulated the possibility of the self-repair.

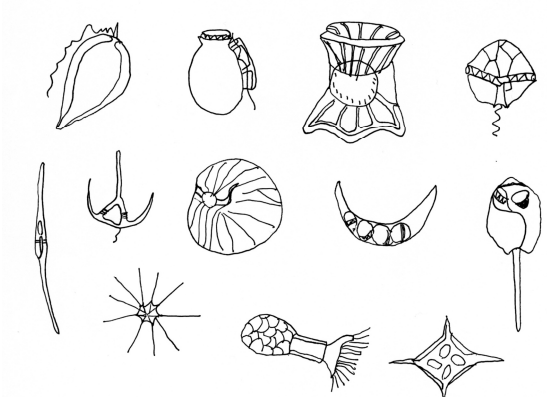

Fig. 1. Various shapes of the unicellular organism

With the real living organism, all forms are not described in DNA, and it is thought that the physical phenomena such as the diffusion of the chemical substance were used in living cells. For this reason, we considered not only the state transition rules but also the concentration diffusion of the field. Thus our model was able to simulate morphogenetic formation in few state transition rules and few parameters of concentration diffusion equations.

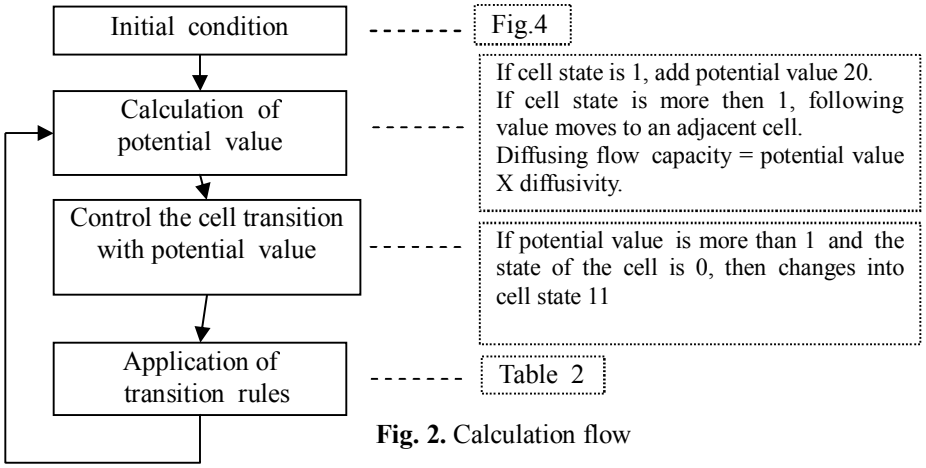

Fig. 2. Calculation flow

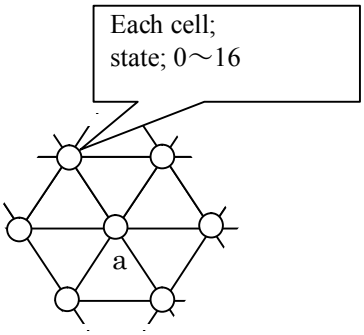

Fig. 3. Triangle grid model

The microbes such as protists create a variety of shapes by a single cell or a few cells (Fig.1). As trial simulation cases, we simulated the shape similar to various form of the microbe.

3 RESEARCH METHOD

3.1 Cellular automaton model

A two-dimensional hexagonal grid model was used in this study (Fig.3). The cell automaton was constructed according to the transition rules so that the state of the next step was determined by the state of the cell itself and the states of the six neighboring cells. Each cell had a state (0–16 states), Table 1 shows the content of 16 states.

Figure 2 shows the calculation flow. In a hexagonal grid, the calculations start from a certain initial condition. We calculates the potential value of gird fields, and control the cell transition with potential value. Then, we applied the transition rules, and settled the total states in all cells.

3.2 Transition rules

The transition rules are presented in Tables 2. We have not yet discovered a method with which to derive transition rules automatically according to a uniform law. Therefore, we constructed transition rules step-by-step according to the movements of the automaton.

3.3 Initial conditions

Figure 6 shows the notation of initial condition. Initial condition is consisted of 7 cells. Central cell is state 1 which has initial potential value. Around the central cell, we set 6 initial cells, which have state from 2 to 6, expressing by six columns of numerical value.

Table 1. States of cell

Cell state	Content	Color
①	cell nucleus	purple
②	cellular cytoplasm	maroon
③	cellular cytoplasm	olive
④	cellular cytoplasm	yellow
⑤	cellular cytoplasm	cream
⑥	cellular cytoplasm	white
⑦	cellular cytoplasm	skyblue
⑧	cellular cytoplasm	lime
⑨	cellular cytoplasm	green
⑩	cellular cytoplasm	pink
⑪	diffusion reaction place	gray
⑫	cell membrane	red
⑬	flagellar	dark blue
⑭	flagellar	peal
⑮	flagellar	aqua blue
⑯	flagellar	blue

Table 2. Transition Rule

	Central Cell	Conditions of six neighborhoods	Transition of central cell (state)	supplemental remarks
1	⑪	②～⑥=1、⑧=2	⑦	formation of cell cytoskeleton
2	⑪	②～⑥=1、⑧=0	⑦	〃
3	⑦	②～⑥≧2	⑪	〃
4	⑪	②～⑥=2	⑧	〃
5	⑦	⑪≧3、ⓜ(m=3～6)=1	ⓜ-1	〃
6	⑦	⑦=2、ⓜ(m=3～6)=1	ⓜ-1	〃
7	⑦	②≧1	⑧	〃
8	⑪	②≧1	⑧	〃
9	⑪	⑧=2、⑪≧2	⑨	〃
10	⑪	⑧=1、⑨=1	⑨	〃
11	⑪	⑨≧2、⑪≧1	⑩	formation of cell membrane
12	⑪	⑨≧1、⑩≧2	⑫	〃
13	⑩	⑨≧1、⑪≧1、⑩=0、⑫=2	⑫	formation of cell membrane patterns
14	⑩	⑨≧1、⑪≧1、⑩=1、⑫=1	⑩	
15	⑩	⑨≧1、⑪≧1、⑩=2、⑫=0	⑫	〃
16	⑫	⑨≧1、⑪≧1、⑩=0、⑫=2	⑫	〃
17	⑫	⑨≧1、⑪≧1、⑩=1、⑫=1	⑫	〃
18	⑫	⑨≧1、⑪≧1、⑩=2、⑫=0	⑫	〃
19	⑪	⑩≧1、⑪≧4	⑬	formation of flagellar
20	⑪	⑫=1、⑬=1	⑭	〃
21	⑪	⑬=1、⑭=1	⑮	〃
22	⑪	⑭=1、⑮=1	⑯	〃
23	⑪	⑮=1、⑯=1	⑬	〃
24	⑪	⑬=1、⑯=1	⑭	〃
25	⑮	⑬=2、⑯=1	⑬	〃
26	⑯	⑬=2、⑭=2	⑭	〃

・The number with the circle shows the state of the cell.(ex. ◎ indicates state 0, ① indicates state 1)
・The description method of the condition ; For example, "①≧ 1" shows that there is more than one cell which is state 1 in six neighborhoods.

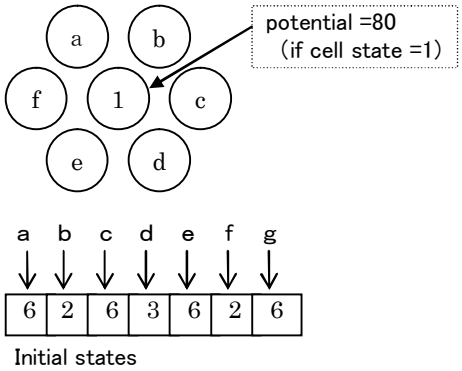

Fig. 4. Notation of initial condition

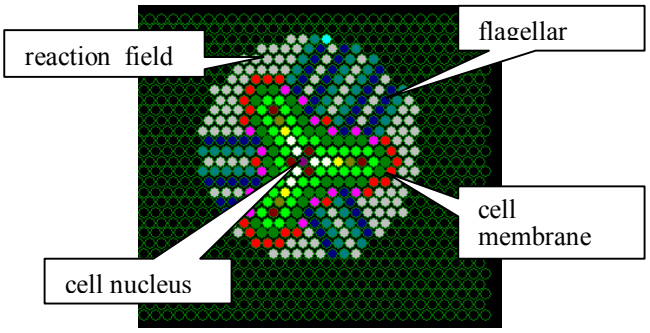

Fig. 5. Calculation result (initial condition 626262)

4 RESULTS

Figure 5 shows the calculation result in the initial case of 626262. A triangular cell is formed and some flagellars are formed. Figure 6 shows the process of cell membrane formation. Figure 7 is change of the result by the difference in initial condition. It is understand that various shapes were formed by the difference in initial condition. Figure 8 shows the change of the result by the difference in cell membrane condition from 13 to 18 in Table 2.

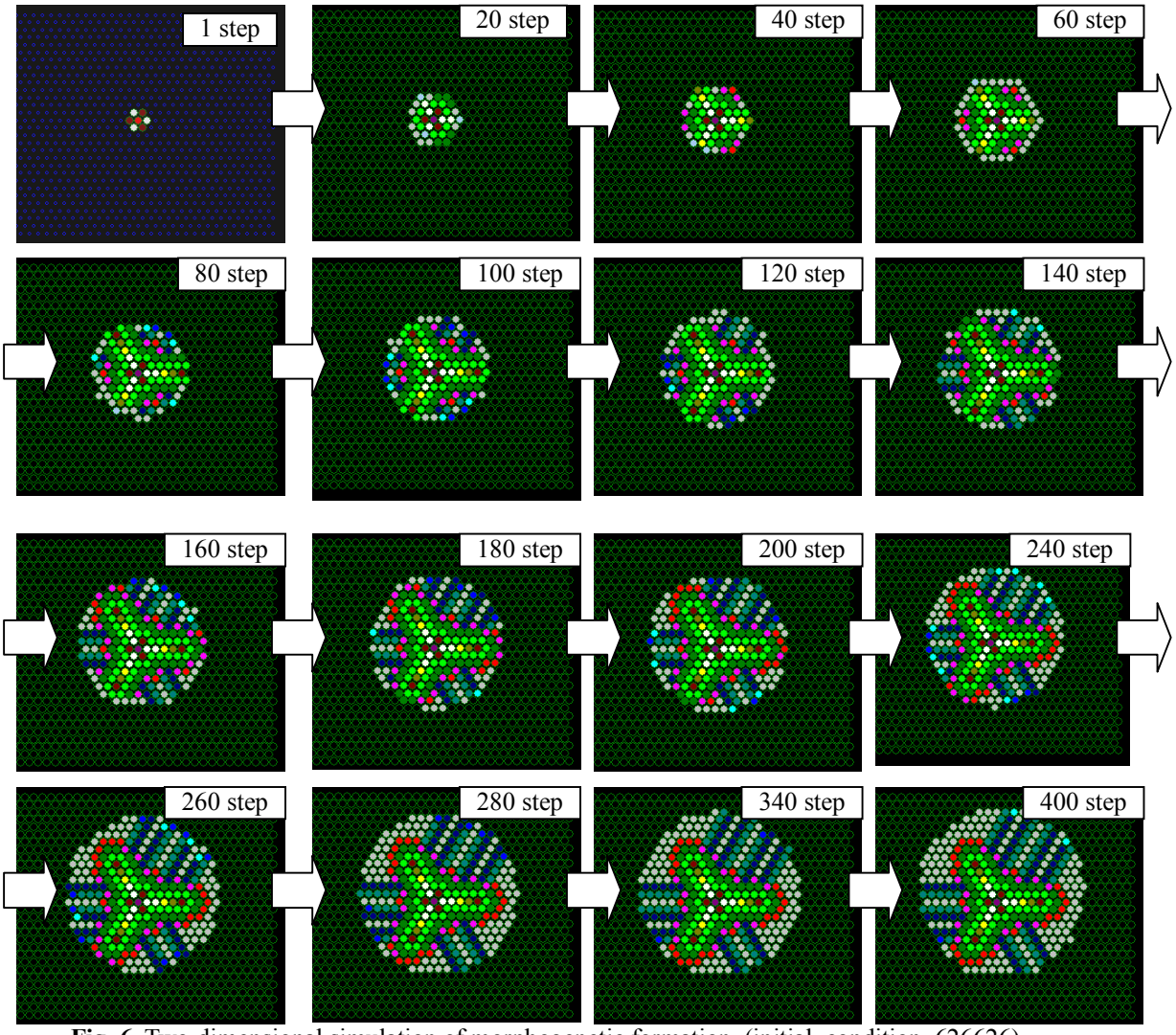

Fig. 6. Two-dimensional simulation of morphogenetic formation (initial condition 626626)

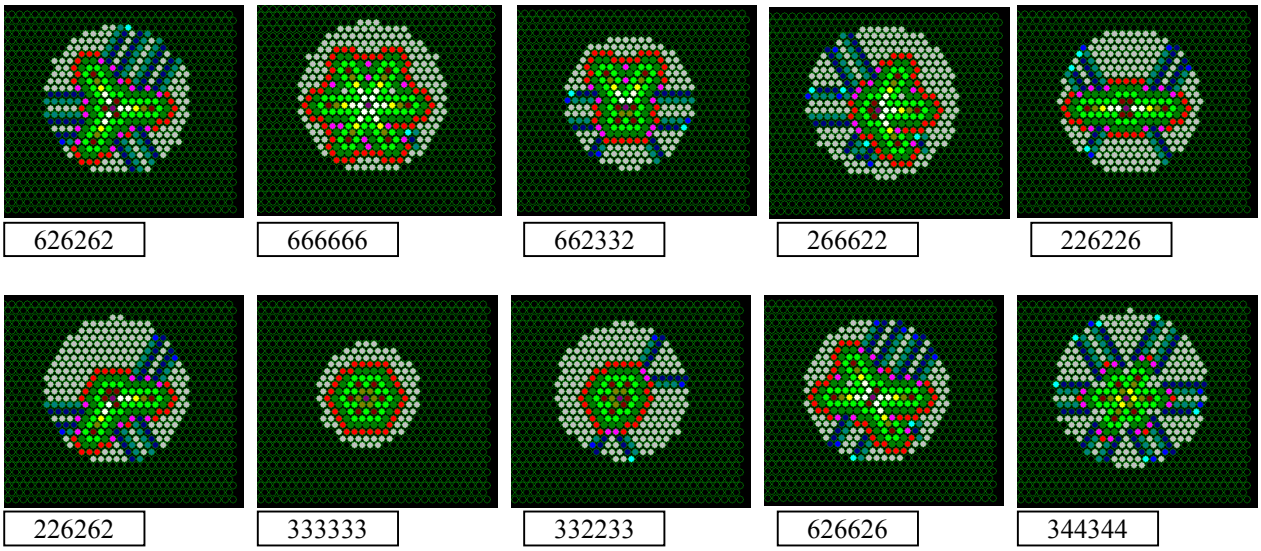

Fig. 7. Two-dimensional simulation of morphogenetic formation
(Change of the result by the difference in initial condition)

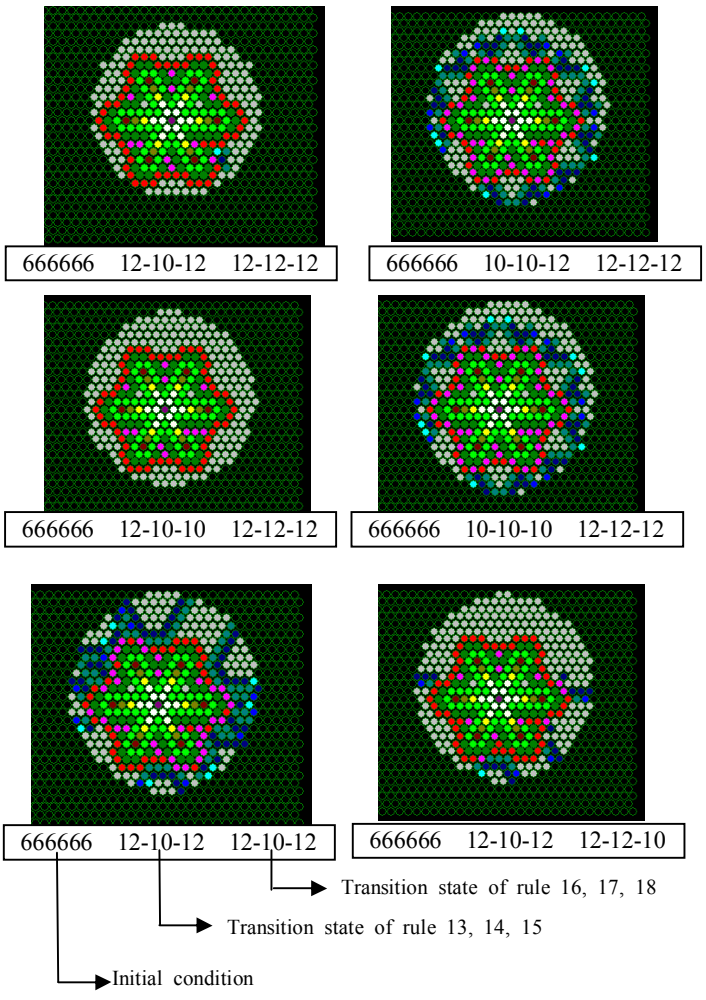

Fig. 8. Two-dimensional simulation of morphogenetic formation (Change of the result by the difference in cell membrane condition)

5 CONCLUSION

Using our model, we confirmed that the variety of shapes was emerged with the slight changes of some parameters value. Future directions are as follows:

- Find other transition rule sets.
- Find a way to automatically derive transition rules based on the uniformity law.
- Apply transition rules to chemical reaction system theoretically.

We believe that transition rules of this model can be applied to simulate self-organizing phenomena in real dynamic chemical reaction environment by applying transition rules determined in this study.

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