Simulation of Self-reproduction Phenomenon of Cells in Two-dimensional Cellular Automata

Takeshi Ishida[1]

[1] Nippon Institute of Technology
ishida06@ecoinfo.jp

Extended Abstract

Understanding the generalized mechanism of self-reproduction is considered to be fundamental for application in various fields such as mass-production of molecular machines of nanotechnology and artificial synthetic of biology (synthetic biology). Furthermore, it is considered that large, complex machine systems of over a certain size are difficult to construct by the top-down approach. Therefore, these complex systems are required to be constructed by the bottom-up approach, by applying the phenomenon of biological self-organization. Thus we have to elucidate not only the details of the cellular reaction network but also the condition for simulating self-organized, self-replicating cells.

Fifty years ago, von Neumann initiated the study of the phenomenon of self-reproduction from a mathematical point of view. This study theoretically proved the possibility of constructing a self-reproducing machine by cell state and transition rules of two-dimensional square cells. On the other hand, Neumann' self-reproducing machine was large in size; therefore, it is difficult to implement this machine perfectly in a computer system (Mange et. al. (2004)). Thereafter, Langton (1989) developed a simple machine capable of self-reproduction abandoning the completeness of Neumann's self-reproducing machine. Although the shape was very simple, the rules of transition are complicated and it could reproduce specific shapes.

In our study, we developed a model for simulating cellular self-reproduction in a two-dimensional Neumann-type cellular automaton. We demonstrated that the following 3 functions can be realized by the transition of 2 adjacent cells in a cellular automaton.

(1) Formation of a border similar to a cell membrane.
(2) Self-replication is achieved while maintaining a carrier containing information (information carrier).
(3) The division of the cell membrane is achieved while maintaining the total structure of the cell.

This study demonstrated the self-reproducing ability of a shape that was similar to that of real cell. This is not a study to clarify all the necessary and sufficient conditions of self-reproduction. It is considered that it is possible to simulate self-replication in a real dynamic chemical reaction environment by applying the transition rules determined in this study.

A two-dimensional triangular grid model was used in this study. The cell automaton was constructed by transition rules such that the state of the next step was decided by the state of the cell and that of 6 neighboring cells. Each cell has a state (0–19) and direction (6 directions) as an attribute. In the triangular grid, calculation starts from a certain initial condition. The transition rules were divided into the following 4 phases: state transition concerning cell membrane formation, division of the information carriers, movement of the information carriers, and formation of the nuclear membrane surrounding the information carriers. In other words, first we applied transition rules of cell membrane formation and settled the total states in all cells. Then, we applied the transition rules for the division of information carriers, following which we applied the transition rule of movement of the information carriers and formation of the nuclear membrane.

Using the model mentioned above, we demonstrate a calculation result with transition rules and the initial condition. Our model was capable of producing a self-reproducing phenomenon in a cell-like shape with few state transition rules (Figure 1).

References

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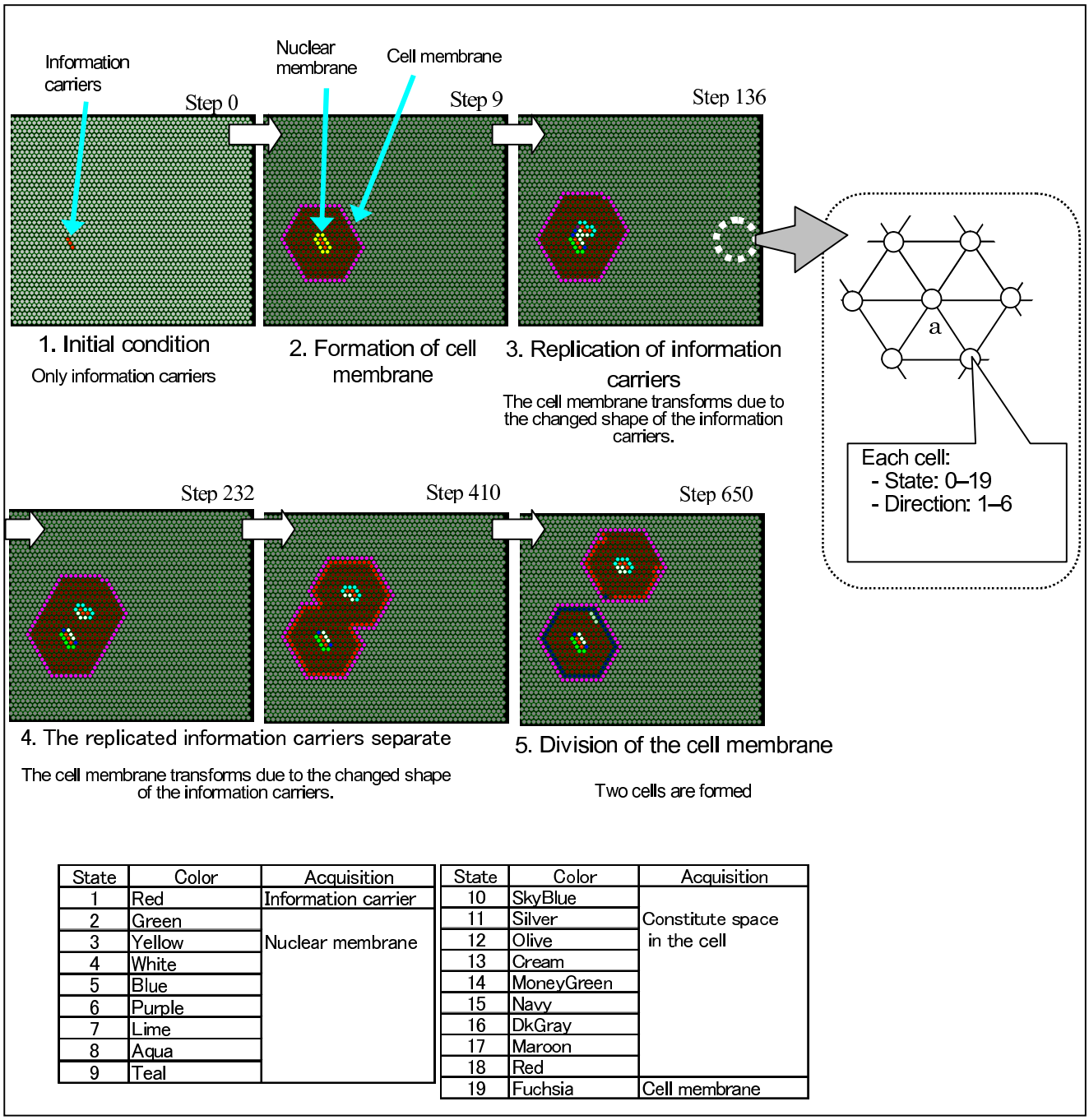

State	Color	Acquisition
1	Red	Information carrier
2	Green	Nuclear membrane
3	Yellow	
4	White	
5	Blue	
6	Purple	
7	Lime	
8	Aqua	
9	Teal	

State	Color	Acquisition
10	SkyBlue	Constitute space in the cell
11	Silver	
12	Olive	
13	Cream	
14	MoneyGreen	
15	Navy	
16	DkGray	
17	Maroon	
18	Red	
19	Fuchsia	Cell membrane

Figure 1 Results of a cell-type self-reproducing two-dimensional cellular automaton. Pink grids are cell membranes, and central red grids are information carriers. This figure shows the process of formation of cell membrane, and the process of division of the information carriers with the cell membrane.