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Simulation of self-reproduction phenomenon of cells in two-dimensional hybrid-cellular automata model

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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. We developed a model for simulating cellular self-reproduction in two-dimensional cellular automaton. We demonstrated that the following 3 functions can be realized. (1) Formation of a border similar to cell membrane. (2) Self-replication is achieved while maintaining a carrier containing information. (3) The division of the cell membrane is achieved while maintaining the total structure. Furthermore we constructed a hybrid cellular automaton model. To reduce the transition rules number, we considered not only the state transition rules but also the concentration diffusion of the Gray Scott model, which emerges self-reproduction phenomenon with certain parameters.

Keywords: self-reproduction, cellular automaton, cell division, Gray Scott model

I. INTRODUCTION

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 real cellular reaction network but also the necessary conditions for self-organized, self-replicating cells.

Fifty years ago, von Neumann[1] initiated the study of self-reproduction model from a mathematical view point. 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 [2]. Thereafter, Langton[3] developed a simple machine capable of self-reproduction abandoning the completeness of Neumann's machine. Although the shape was very simple, the rules of transition are complicated and it could reproduce specific shapes.

In our previous study[4], we developed a model for simulating cellular self-reproduction in two-dimensional cellular automaton. We demonstrated that the following 3 functions can be realized by the transition of two adjacent cells.

(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 living cell. Figure 1 showed the results of a cell-type self-reproducing two-dimensional cellular automaton. This is not a study to clarify all the necessary and sufficient conditions of self-reproduction. It is considered that it is

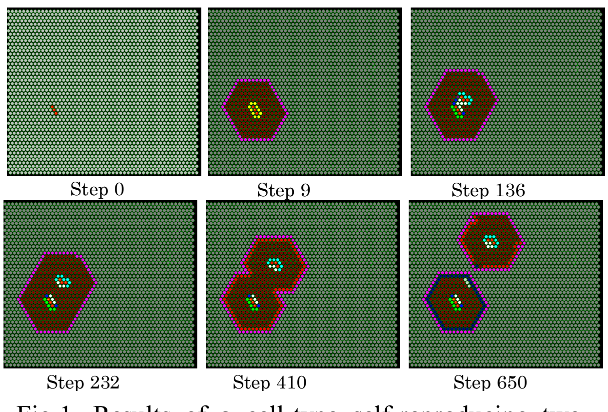

Fig.1. Results of a cell-type self-reproducing two-dimensional cellular automaton [4]

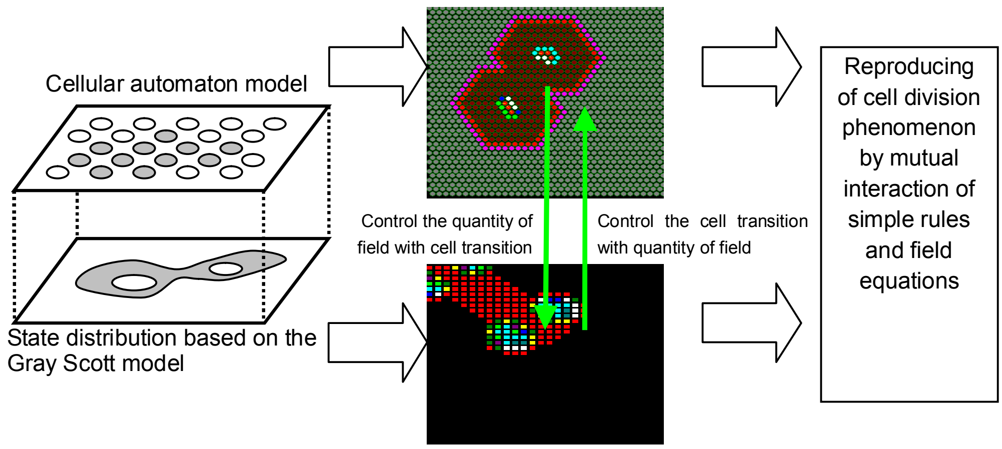

Fig.2. Outline of hybrid cellular automaton model

possible to simulate self-replication in a real dynamic chemical reaction environment by applying the transition rules determined in this study.

II. OBJECTVE

In this study, we constructed a hybrid cellular automaton model. Figure 2 shows the outline of hybrid model. To reduce the transition rules number, we considered not only the state transition rules but also the concentration diffusion of the field. We chose the Gray Scott model, which emerges self-reproduction phenomenon with certain parameters. In this hybrid model, information carriers activate the trigger of the self-reproduction phenomenon of the Gray Scott model, and cell membrane was formed by a part of the specific concentration of Gray Scott model. Using this model, we reduced the number of transition rules.

III. RESARCH METHOD

1. Cellular automaton model

A two-dimensional triangular grid model was used in this study (Fig.3). The cell automaton was constructed by transition rules such that the state of the next step was decided by the state of the own 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: 1) state transition concerning cell membrane formation, 2) division of the information carriers, 3) movement of the information carriers, and 4) 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.

To cause objective state transitions of the cellular automata, these rules cause unexpected side effects. We divided the transition into 4 phases and discovered the transition rules because the discovery of whole transition rules was difficult at a time.

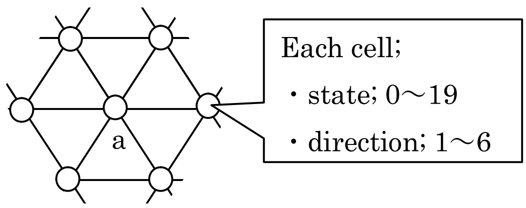

Fig.3 Triangular grid model in this study

2. Gray Scott model

Concerning this cellular automaton model, cell transitions patterns are similar to the physical phenomena. Thus we considered the possibility of substitute of transition rules to non-liner quantity model like Gray Scott model. Equations of Gray Scott model is as follow. Self-replication patterns are caused under certain conditions (Du = 0.04, Dv = 0.02, F = 0.02, k = 0.06, in this study).

$$\frac{\partial V}{\partial t} = D_{\alpha}\Delta V - U^2 V + F(1-V) \tag{1}$$

$$\frac{\partial U}{\partial t} = D_U \Delta U + U^2 V - (F+k)U \tag{2}$$

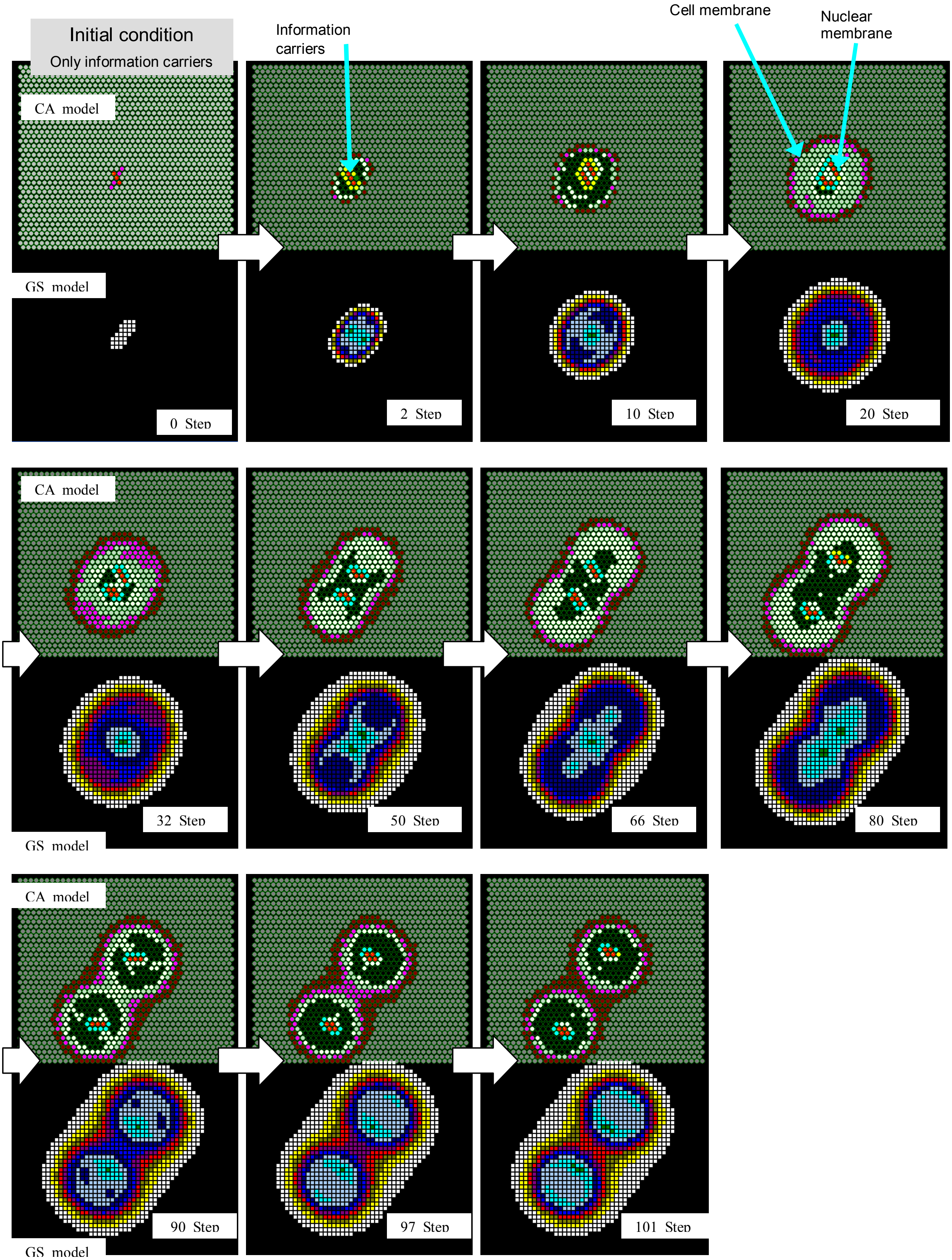

Fig.4 Results of hybrid cellular automaton model

Table.1 Number of transition rules

CA model		Hybrid model	
Process	Number of transition rules	Alternate physical phenomenon	Number of transition rules
Application of transition rules of cell membrane formation	34	Gray Scott Model	4
Application of transition rules of information carriers division	17	—	17
Application of transition rules of information carriers movement	12	—	12
Application of transition rules of nuclear membrane formation	13	—	5

3. Transition rules

Each cell was renewed by transition rules and the state of the next step was decided by the state of the cell and that of 6 neighboring sites. It is not found the method to derive transition rules according to uniformity law automatically at this time. Therefore, we constructed step-by-step transition rules according to the movement of the cell in the automaton.

In this hybrid model, firstly information carriers activate the trigger of the Gray Scott model. States of cell membrane appears under certain concentration of Gray Scott fields. The movement of nuclear membrane was controlled by concentration of Gray Scott fields.

IV. RESULTS

Figure 4 shows the process of formation of cell membrane, and the process of division of the information carriers with the cell membrane. Thus, we were able to replicate the phenomenon of cell-like division.

Table1 shows the number of transition rules of cellular automaton model and hybrid model. Using this hybrid model, we reduce the number of transition rules.

V. CONCLUSION

Our model produced a self-reproducing phenomenon in a cell shape with few state transition rules. 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 particle collision theoretically.

We believe that transition rules of this model can be applied to simulate self-replication phenomena in a real dynamic chemical reaction environment by applying transition rules determined in this study. We plan first to achieve cell-division simulation of a discrete particle reaction. It is comparatively easy to replace state transition rules with collision / reaction rules of discrete particles.

We next plan to achieve cell-division simulation of continuous chemical reaction simulation. We can convert discrete particles rules to chemical equations.

REFERENCES

[1] J. von Neumann; Theory of Self-replicating Automata, University of Illinois Press, 1966

[2] D. Mange, A. Stauffer, L. Peparodo, and G. G. tempesti; A Macroscopic View of Self-Replication, Proceeding of the IEEE, vol.92, No.12, Dec. 2004

[3] C. Langton ed, Artificial Life, 1/48, Addison-Wesley, 1989

[4] Takeshi Ishida, Simulating self-reproduction of c ells in a two-dimensional cellular automaton., Journ al of Robotics and Mechatronics, Vol.22, No.5, pp.6 69-676, 2010