Self-reproduction on 1-bit communication cellular automata

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Abstract

Many researchers have constructed a self-reproduction model on cellular automata so far. C. G. Langton constructed a simple model on the 2-D cellular automata, and it is a *dynamic-loop* [4]. We consider embedding the Langton's model in 1-bit communication cellular automata. The 1-bit communication cellular automata are restricted communication-capacity to 1-bit. The Langton's model has 8 internal states and generally it is impossible to represent 8 by 1-bit. Thus it occurs time-loss in communication of information. In this paper, we will embed Langton's model in 1-bit communication cellular automata without time-loss. However the embedding model has a large number of internal states, so we construct the second model. In the second model, by excluding some properties of Langton's model, we reduced internal states.

1 Introduction

Studies for life phenomena have been made for many years. Especially, structures of many lives have been made clear by progress of technology from middle of 20th century. However, evolution process of life phenomena and process that cells constitute a large scale structure according to genes are not clear.

Some of researches, which are actively done in artificial life, are about self-reproduction of life. Especially, a lot of self-reproduction models on 2-D cellular automata have been suggested by many researchers [2-4, 6, 7, 9, 10]. A self-reproduction model constructed by C. G. Langton on 2-D cellular automata is very simple. It has a *dynamic-loop* structure. In this paper, we will embed the simple model in communication-restricted cellular automata.

2 Self-reproduction loop

At first, self-reproduction model was suggested by John von Neumann. Neumann considered a machine that has information for self-reproduction, and replicates itself, and then he get an idea. It is that a universal machine is able to do such behavior. Moreover, for simplification of problem, Neumann used the 2-D cellular automata and he constructed an universal machine that has 29 internal states on 2-D cellular automata [6].

The 2-D cellular automata are a parallel processing model where finite automata are placed as plane. We call each automaton cell. Each cell has a set of internal states Q and a transition function δ such that $Q^4 \rightarrow Q$. In the 2-D cellular automata, inputs of transition function are states of neighbors (north, west, east, south and itself). Thus, transition function δ on 2-D cellular automata is defined as the following.

$$\delta(q_n, q_w, q, q_e, q_s) = q' \qquad (1)$$
$$(q_n, q_w, q, q_e, q_s, q' \in Q)$$

Codd designated that Neumann's model can behave in 8 internal states [3], and Serisawa designated that Neumann's model can behave in 3 states (Neumann neighbors) or 2 states (Moore neighbors) [9, 10].

On the other hand, Langton considered a more simple model, because cells in nature don't seem to be *universal machine*. So Langton constructed such self-reproduction model on 2-D cellular automata. Langton's model uses 8-states per cell [4]. We call Langton's self-reproduction model on 2-D cellular automata *Langton-Loop* by the shape. Figure 1 shows transition of *Langton-Loop*, where t means time. *Langton-loop* exists in cellular space filled by state "0" cells. The state "0" is called quiescent state.

Langton-Loop is surrounded by cell wall states. We call a part which is surrounded cell wall inner-loop. *Langton-Loop* reproduces a pattern by state transitions in inner-loop. Here, we consider separating *Langton-Loop* into *loop-part* and *arm-part*, to assist understanding transition of *Langton-Loop* (Fig. 2). By the signals from *loop-part*, *Langton-Loop* extends *arm-part* and builds left hand corners 3 times at the time which is decided beforehand.

A signal to *arm-part* consists of five state "7" and two state "4". *Loop-part* send out these states to the

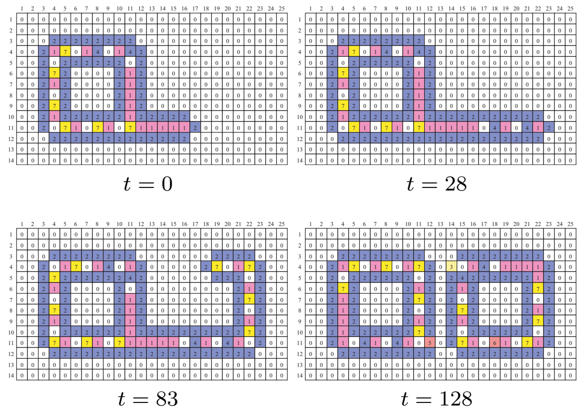


Figure 1: Langton-Loop

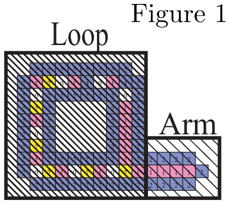


Figure 2: *Loop-part* and *arm-part*

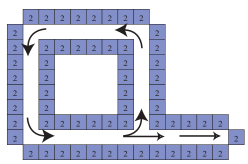


Figure 3: Direction of signals

end of *arm-part* (Fig. 3). When state "7" reaches the end of *arm-part*, *arm-part* can extend length of one cell.

By state "4" reaches the end of *arm-part* two times, *arm-part* turns. The first state "4" changes a direction of *arm-part*'s extension to left hand by using temporary state "3". Then, when second state "4" reaches a cell which assumes state "3", the state "3" cell changes state to state "1". So *arm-part* can change direction of extension.

By iteration of this action, *loop-part* is constructed. For that purpose, *loop-part* must continue sending the signal which consists state "7" and state "4" to *arm-part*. This action is done by sending state "7" and state "4" to *arm-part*, and feed back into *loop-part* at once (Fig. 3).

3 Self-reproduction loop on 1-bit communication cellular automata

3.1 2-D 1-bit communication cellular automata

The 1-bit communication cellular automata were suggested by Mazoyer [5] and Umeo [8]. The 2-D 1-bit communication cellular automata are 2-D cellular automata that are restricted communication-capacity to 1-bit. Figure 4 shows structure of 2-D 1-bit communication cellular automata. Each cell of 2-D 1-bit communication cellular automata has a set of inner-states

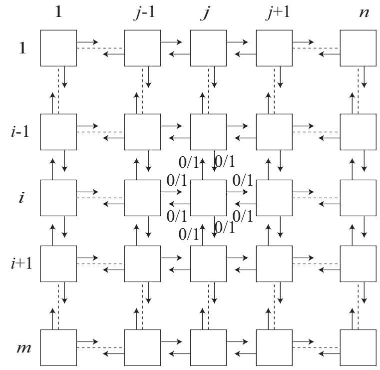


Figure 4: 2-D 1-bit communication cellular automata

Q and transition function δ, as well as 2-D cellular automata. Transition function δ in 2-D 1-bit communication cellular automata is defined to the following, by the property.

$$\delta(b_n, b_w, q, b_e, b_s) = (b'_n, b'_w, q', b'_e, b'_s) \quad (2)$$

Where $q, q' \in Q$ and $b_n, b_w, b_e, b_s, b'_n, b'_w, b'_e, b'_s \in \{0, 1\}$. In 1-bit communication cellular automata, an information from a north, south, east, west cell is always 0 or 1.

3.2 Self-reproduction model M_α

In this paper, we suggest two self-reproduction models. We call first model M_α and second model M_β. At first, we will explain about M_α

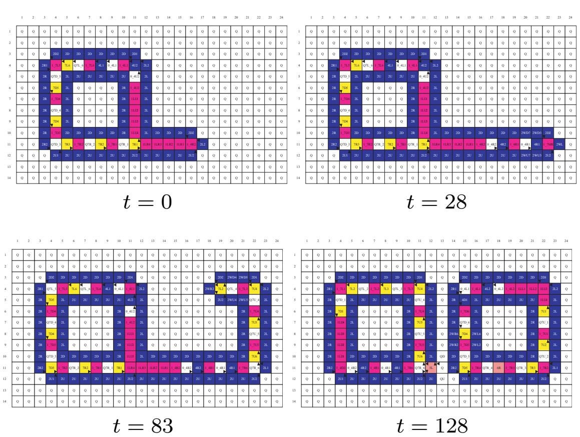


Figure 5: Self-reproduction model M_α

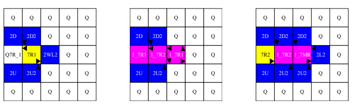
We constitute M_α by embedding Langton's model to 1-bit communication cellular automata. M_α has 263 internal states. Figure 5 shows model M_α. 1-bit signal is represented by small triangles in the figure. If a small triangle exitst, it means sending 1 signal and a small triangle don't exist it means sending 0 signal.

M_α also has *arm-part* and *loop-part* and performs as *Langton-Loop*. All cells except reproducing pattern are filled by quiescent state.

When an algorithm is executed on 1-bit communication cellular automata, there are problems proper to 1-bit communication cellular automata. One of problem is number of transition rules an state. Since a cell on 1-bit communication cellular automata changes the state by its state and 1-bit signals from neighbors, the cell may refers a same transition rule, even if neighbor's state is different. We solve the problem as following.

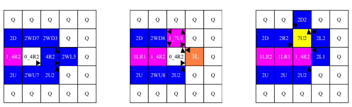
M_α extends *arm-part* by cycling signals in *loop-part*, as well as *Langton-Loop*. For above problems, each cell has to recognize its own part, a junction of *loop-part* and *arm-part*, the corner of *arm-part*, the termination of *arm-part*, or others.

At first, we explain about a termination of *arm-part*. The cell at termination of *arm-part* recognizes its part by receiving 1-bit signals by forward and left, right cells against the direction of signal. The cell at termination of *arm-part* extends *arm-part* by "7-0" signal (Fig. 6) and makes corner by "4-0" signal.



$t = t_0$ $t = t_0 + 1$ $t = t_0 + 2$

Figure 6: Extension by "7-0" signal



$t = t_0$ $t = t_0 + 1$ $t = t_0 + 2$

Figure 7: Makeing corner by "4-0" signal

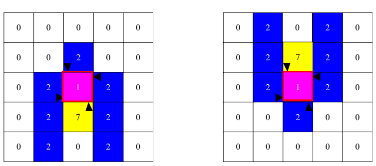
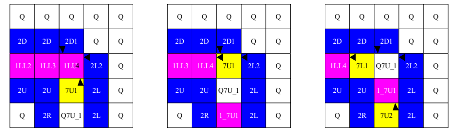


Figure 8: No information of the direction

However, a bad effect occurs by above problem. Although at both two cases in Fig. 8, the cell which assumes state "1" recognizes that its position is termination of *arm-part*, the cell doesn't recognize the direction of extension. Because, the cell doesn't have information of the direction. So, we add information of the direction to each state. For example, state "2" is transformed into "2U", "2D", "2R", "2L"(each state means north, south, east, west). By this transformation, each cell recognizes the direction of signals from an internal state.

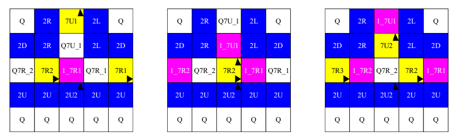
The cell at the corner of *loop-part* recognizes that it is the corner of *loop-part* by receiving 1-bit signal from the cell on the forward and right toward the direction of signals. So the cell can change the direction of signals to the left toward (Fig. 9).



$t = t_0$ $t = t_0 + 1$ $t = t_0 + 2$

Figure 9: Recognition of corner

A cell at junction of *loop-part* and *arm-part* recognizes that itself by receiving 1-bit signal from the cell on the right toward the direction of signals. So, the cell can send signals to *loop-part* and *arm-part* (Fig. 10). M_α can self-reproduce by these actions without time-loss.

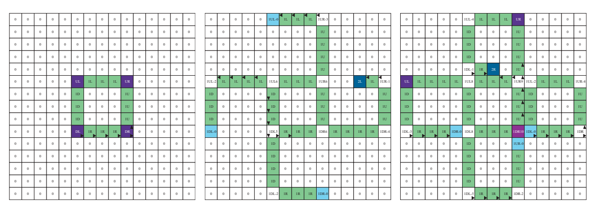


$t = t_0$ $t = t_0 + 1$ $t = t_0 + 2$

Figure 10: A junction of *loop-part* and *arm-part*

3.3 Self-reproduction loop M_β

The second model M_β has 77 internal states. Figure 11 shows action of M_β. M_β also has *loop-part* and *arm-part*, cells surrounding pattern assume quiescent state. The algorithm of reproduction is also same; by sending signal from *loop-part*, *arm-part* is extended and make a corner. However, as Fig. 11 shows, there are some different points.



$t = 0$ $t = 45$ $t = 69$

Figure 11: Self-reproduction model M_β

M_β is different from *Langton-Loop* in three points. The first point is that M_β doesn't have cell wall state which is state "2" in *Langton-Loop*. The second point is that M_β reproduces to four direction (north, south, west, east) at the almost same time. The third point is that signals which cycles in *loop-part* for reproduction are a sequence of 1-bit signal.

The initial pattern of M_β is square and the length of a side is more than two cells and arbitrary. Reproduced loops have same size as well as initial pattern. Initial pattern must have 1-bit signals which can be propagated unti-clockwise and have length of a side.

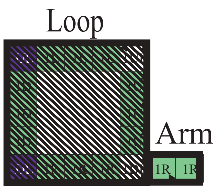


Figure 12: *Loop-part* and *arm-part*(M_β)

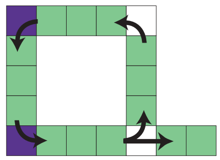


Figure 13: Direction of signal

In this model, *arm-part* extends length of one cell by a 1-bit signal (Fig. 14). While 1-bit signal continuously send to the end of *arm-part*, *arm-part* extends. But, when 1-bit signal interrupts, the end of *arm-part* assumes a state which can build a left hand corner. As a result, when another signals arrive to the end of *arm-part*, *arm-part* extends to left hand (Fig. 15).

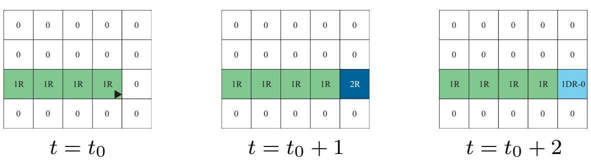


Figure 14: Extension of *arm-part*(M_β)

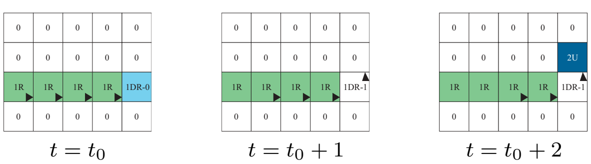


Figure 15: Changing direction of the line(M_β)

On the other hand, each corner cell of *loop-part* sends two signals, when each corner cell gets input signal. These two signals which are duplicated at junction of *loop-part* and *arm-part* are respectively propagated to *loop-part* and *arm-part* as well as *Langton-Loop* (Fig. 13). Thus, corner cells of *loop-part* have function that controls signals sent *arm-part*. Continuous 1-bit signals which are sent to *arm-part* are sent 5 times, to build new *loop-part*. Signals from once to fourth times have a function which extends *arm-part* and builds new *loop-part*. Signal of the fifth times has a function that gives ability of self-reproduction to new *loop-part*. Therefore, signals of the fifth times will have been propagated in new *loop-part*. Thus, when signals of the fifth times have inputted to new *loop-part*, self-reproduction that includes an ability of self-reproduction is finished. A corner cell that have sent signals 5 times assumes a state that does not send signal to *arm-part*.

4 Conclusion

In this paper, we have constructed two models which behaves on 1-bit communication cellular automata as well as *Langton-Loop*. The model has 263 internal states. And by excludting some property of *Langton-Loop*, we get a model that has 77 internal states. These models designate that the relation of communication capacity and internal states has a trade-off, we want to analyze strictly as well.

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