IEICE Proceeding Series

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Vol. 2 pp. 57-60
Publication Date: 2014/03/18
Online ISSN: 2188-5079

2013 International Symposium on Nonlinear Theory and its Applications
NOLTA2013, Santa Fe, USA, September 8-11, 2013

Autonomous formation of object clusters on vertical plane

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Abstract—In this paper, we propose a discrete version of distributed building model inspired by wasp colonies. We define fundamental event rules in a cellular world, and introduce an action rule of distributed autonomous agent. Robot decides its action rule following by the local configuration, without any communication between agents. Then we show that the robot build characteristic architecture in some rule.

1. Introduction

Ant colonies, and more generally social insect societies construct complex structure. These agents do not communicate with each other, and have no global representation of the architecture they are building, do not possess any plan or blueprint and can only perceive the local configuration of surrounding them. From the study of nest building arises the concept of sitgmergy: it describes an indirect communication which is mediated by the environment. This concept has been considered important[1][2][3].

Meanwhile, cellular automata approach, which was first proposed by Stephen Wolfram [4][5], has been considered to be an excellent way to analyze a great many natural phenomena. Defining a local rule between neighbors global pattern generation has been investigated in many scientific areas.

We first propose to assume that everything happens on a discretized state space. Then we define fundamental event rules in this cellular world, and introduce a robot and a block. Every robot decides its action rule from neighbor configuration without any direct communication between agents. In this paper, we propose 4 robot action rule, 0:Load, 1:Unload, 2:Move, 3:Turn. Then, we show a specific formation investigating all patterns generated from possible transition rules.

This paper is organized as follows. Section 2 prepares basic properties hold on discretized space model, and introduces a robot and a block. Then, we calculate totalistic rules in proposed model. Section 3 picks up some specific object formation at some rules. Conclusions and future works are described in Section 4.

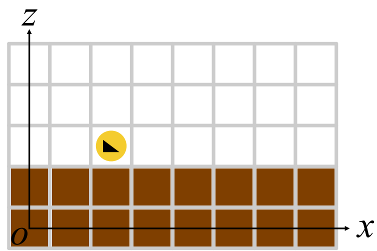


Figure 1: Coordinate setting in the cellular space.

2. Rules of the discrete world

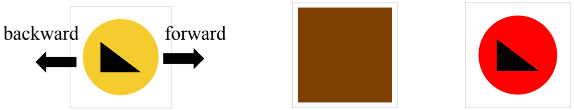
In this section, we consider a discrete version of three-dimensional object formation.

2.1. Fundamental setting in the cellular world

This paper tries to approach 3-dimensional object clustering as simple as possible. In this paper we consider object clustering in $x - z$ plane , as the first step to achieve it. Suppose a tessellation of the 2-dimensional Euclidean space $\mathbb{R}^2$ with *unit square*, as shown in Figure 1. Of course, there is not the only choice, the cells can be hexagonal and other shapes as well. Let O be the origin, which coincides with the center of a hexagon. The x-axis is set as a line passing through O and is perpendicular to an edge, while z-axis passes through on of its vertex.

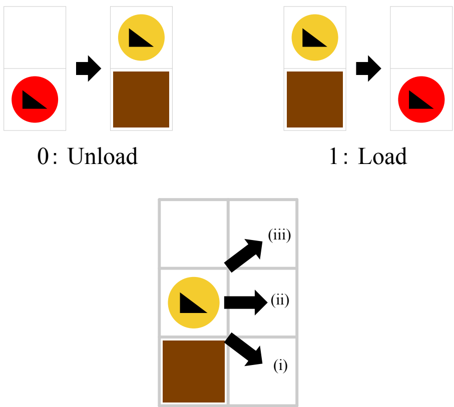
The world in concern consists of the square cellular space, robots and blocks. A robot occupies a cell (Figure 2(a)), and has 2 directions (Forward and Backward). For example, the direction of robot is right in Figure 2(a). A block also occupies a cell (see Figure 2(b)). A block does not have its orientation.

State of the world changes stepwise. Every robot changes its state either of the action rules defined later, and picks up or drops one block. Every block, which is immobile in itself, can be carried by a robot. Only in carrying one block by robot, two objects (one robot and one block) can occupy a single cell (see Figure 2(c)).



(a) A robot (b) A brock (c) A robot carrying a brick

Figure 2: Objects



0: Unload 1: Load 2:Move

Figure 3: All actions

2.2. Rules for robot action

A robot chooses its action rules from following 4 action rules:

Action rule

0:Unload Drop the block at the current cell, then climb onto it (Figure 3(0)).

1:Load Pick up the underneath block, then go down to the empty cell (Figure 3(1)).

2:Move Step forward to the lowest empty cell (Figure 3(2)).

3:Turn Change its direction to the opposite direction.

2.3. Definition of neighbor cells

A robot only perceives configurations of neighbor 4 cells shown in Fig. 4; From the perception of the neighbor configurations, every robot gets the information of the height difference to the neighbor cells; i.e.; neighbor configurations are higher, lower, or equal height comparing to the cell that the robot exists.

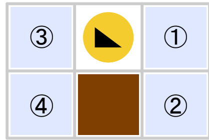
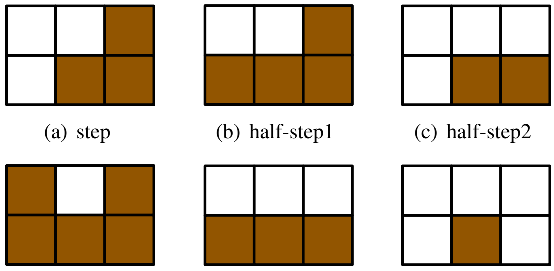


Figure 4: 4 neighbor configurations that robots perceive.



(a) step (b) half-step1 (c) half-step2 (d) convex (e) flat (f) concave

Figure 5: The all possible patterns of local blocks

2.4. Possible rules

First, we consider possible neighborhood-state. Possible neighborhood-states are calculated at $2^4 = 16$. But, we reduce the 4 state that block exists on an empty cell; e.g.; neighbor 3 occupies a block, but neighbor 4 occupies no block. And, we also reduce a half state ignoring the direction of robot. Thus, possible neighborhood-state in the cellular space is calculated at 6 in Figure 5.

Second,we consider robot action rules. Every robot decides its action rules as follows. First a robot selects action rule 0, rule 1, or rule 2. If a robot decides to Unload at action rule 0, and carries no block, this robot changes its action rule to rule 2. If a robot decides to Load at action rule 1, and carries one block, this robot changes its action rule to rule 2. If a robot cannot move at action rule 2 due to neighborhood-state, this robot changes its action rule to rule 3.

Every robot changes its action rule (0:Unload, 1:Load, 2:Move) for the 6 neighbor configurations of Figure 5(a)-(f), respectively. Thus, there are $3^6 = 729$ such totalistic rules. For example, if robot decides its rule as 120102 at 6 neighborhood-state shown in Table 1, the number given above is the value 416 in base 3 and so this automaton is labeled Code 416.

3. Autonomous formation

In this section, we pick up several cluster formations generated from 729 possible rules.

3.1. Code 416

First, we suppose the field $100 \times 50 = 5000$ cells; 20 robots are randomly positioned at constant intervals in ini-

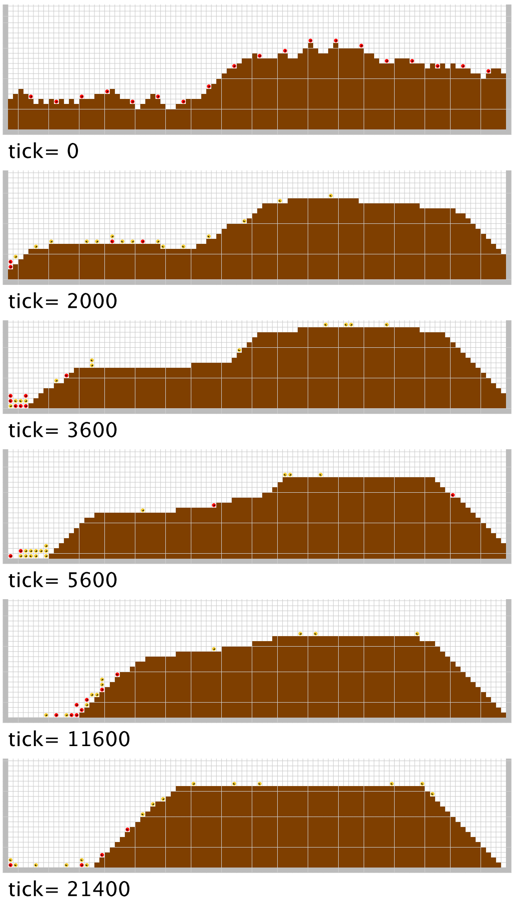


Figure 6: The process of clustering simulation by 20 robots in Code 416. The top figure shows the initial state.

tial states. On the field boundary, robots are forced to Turn. Initial structure is set to random distribution whose height difference to neighbor cells is lower than one block.

Figure 6 shows the process of clustering when robots change its action as Table 1. It seems that a trapezoid cluster are formed.

(f)	(e)	(d)	(c)	(b)	(a)
Load 1	Move 2	Unload 0	Load 1	Unload 0	Move 2

Table 1: The definition of Code 416 which indicates what action the robot takes baced on each local configuration

3.2. Code 254

We also suppose the field $100 \times 50 = 5000$ cells; 20 robots are randomly positioned at constant intervals in initial states. On the field boundary, robots are forced to Turn. Initial structure is set to random distribution whose height difference to neighbor cells is lower than one block. Figure 7 shows the process of clustering when robots change its action as Table 2. It seems that a triangle structure is formed.

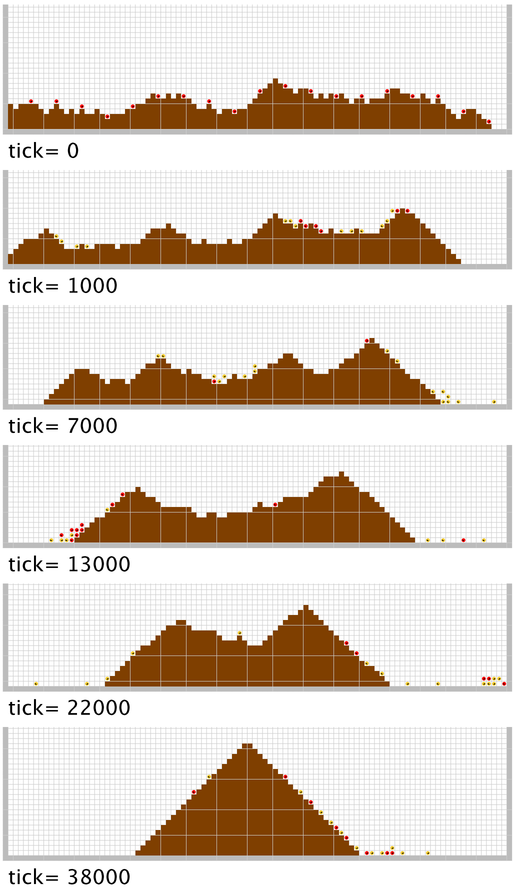


Figure 7: The process of clustering simulation by 20 robots in Code 254. The top figure shows the initial state.

(f)	(e)	(d)	(c)	(b)	(a)
Load 1	Unload 0	Unload 0	Load 1	Unload 0	Move 2

Table 2: The definition of Code 254 which indicates what action the robot takes baced on each local configuration

3.3. Code 308

We also suppose the field $100 \times 50 = 5000$ cells; 20 robots are positioned at constant intervals in initial states. On the field boundary, robots are forced to Turn. Initial structure is set to random distribution whose height difference to neighbor cells being lower than one block. Figure 9 shows the process of clustering when robots change its action as Table 3. Several triangular clusters are formed (see Figure 9). Repeating simulations at different initial states

(f)	(e)	(d)	(c)	(b)	(a)
Load 1	Unload 0	Move 2	Load 1	Unload 0	Move 2

Table 3: The definition of Code 308 which indicates what action the robot takes baced on each local configuration

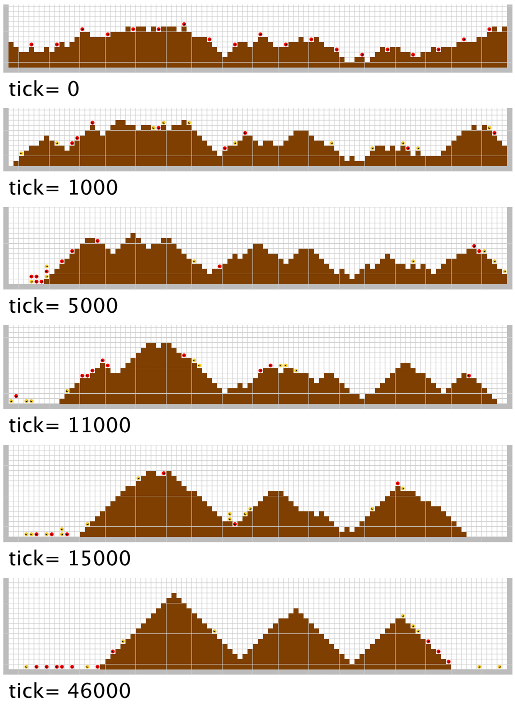


Figure 8: The process of clustering simulation by 20 robots in Code 308. The top figure shows the initial state.

different number of triangular clusters are formed (see Figure 9).

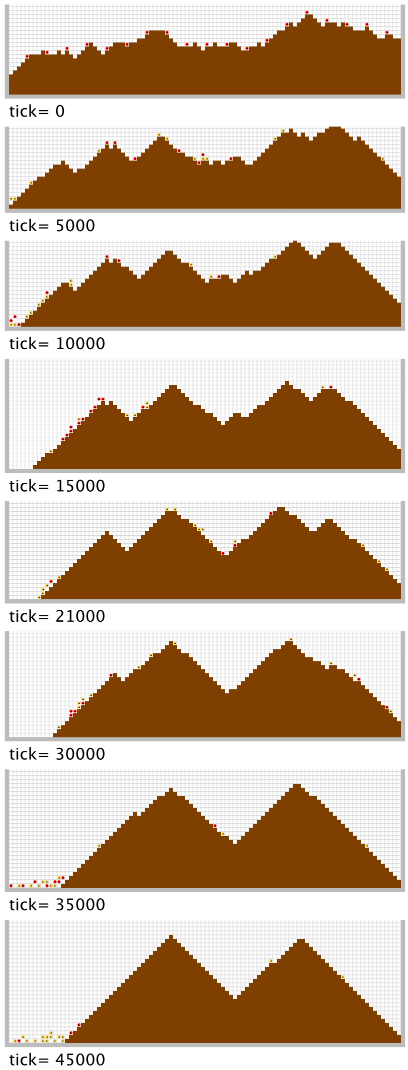


Figure 9: The process of clustering simulation by 20 robots in Code 308. The top figure shows the initial state.

4. Conclusion

In this paper, we proposed a discrete-space version of object formation on vertical plane by autonomous robots by changing actions according to local configuration. From the numerical simulations we observed the different architecture by different robot rules.

Acknowledgments

This research is partially supported by the Aihara Innovative Mathematical Modeling Project, the Japan Society for the Promotion of Science (JSPS) through the "Funding Program for World-Leading Innovative R&D on Science and Technology(FIRST Program)," initiated by the Council for Science and Technology Policy (CSTP).

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