Flying Bit in a Model of Excitable Media on Face-centered Cubic Lattice

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Abstract

Several propagating and stationary patterns have been observed in the model of excitable media on face-centered cubic lattice. In this research, we consider a propagating pattern called type-I glider on the lattice as a flying bit 0. By colliding it with another propagating pattern called type-II glider in the proper configuration, it can be turned at right angles. Colliding a type-I glider with another in the other proper configuration converts it into a type-IV glider which represents a flying bit 1. Furthermore, the collision of a flying bit 1 with a stationary pattern can convert the flying bit 1 into 0. These results lead to the possibility of creating logic gates in excitable media.

Introduction

Excitable media (Greenberg and Hastings, 1978; Gerhardt and Schuster, 1989; Gerhardt et al., 1990c,a,b; Markus, 1990; Tóth et al., 1994; Tóth and Showalter, 1995; Adamatzky, 1998, 2001, 2013) are one of the highest potential substrates for unconventional computing. In this research, we employ three-dimensional cellular automaton (CA) as a model excitable media. For a start, we will try to realize a flying bit and its operations (set/reset) and bend of signal line since these functions are necessary to achieve computation.

Face-centered Cubic Cellular Automaton

We employ face-centered cubic lattice, as depicted in Figure 1, due to its maximal sphere-packing density (Conway and Sloane, 1993). We call CA on face-centered cubic lattice (Preston Jr. and Duff, 1984; Bays, 1987a,b) face-centered cubic CA (FCCA), (Ninagawa, 2018), and Figure 1 illustrates 12 cells adjacent to the central cell 'C.'

Let $s^t(x, y, z) \in \{0, 1, 2\}$ denote the state of the cell (x, y, z) at time t. Our focus centers on the transition function described by the following;

$$s^{t+1}(x, y, z) = F(s^t(x, y, z), n_2^t(x, y, z), n_1^t(x, y, z)), \quad (1)$$

where $n_i^t(x, y, z) \in \{0, 1, \cdots, 12\}$, ($i$=1,2) represents the number of cells with state i among those adjacent to the cell (x, y, z) at time t and F represents a transition function.

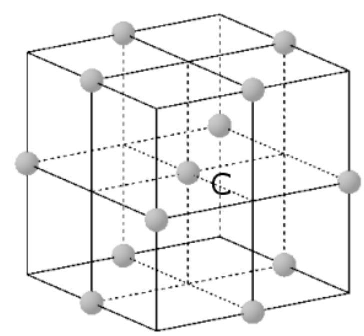

Figure 1: Face-centered cubic lattice.

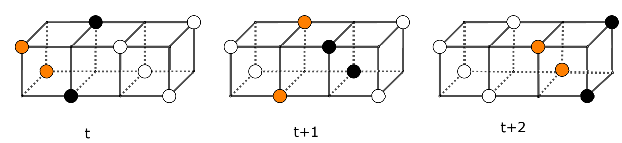

Figure 2: Movement of GI. White, black, and orange sphere represent a cell with state zero, one, and two respectively.

As a preliminary step, let us consider the rules named B2SC3 according to the generation rules nomenclature (Wojtowicz, 3 16);

$$F(0, *, n_1) = \begin{cases} 1 & n_1 = 2, \\ 0 & n_1 \neq 2, \end{cases}$$
$$F(1, *, *) = 2, \quad F(2, *, *) = 0, \quad (2)$$

where '*' means "don't care".

Figure 2 illustrates the motion of a propagating pattern known as a type-I glider or GI (Ninagawa, 2018) within B2SC3. We identify it as a flying bit, representing bit '0.'

While several propagating patterns exist in B2SC3 (Ninagawa, 2024), these rules are deemed "flammable," meaning that collisions between gliders lead to a sudden increase in the number of nonzero cells. To mitigate this "combustibility" in B2SC3, we modify the transition rules from B2SC3

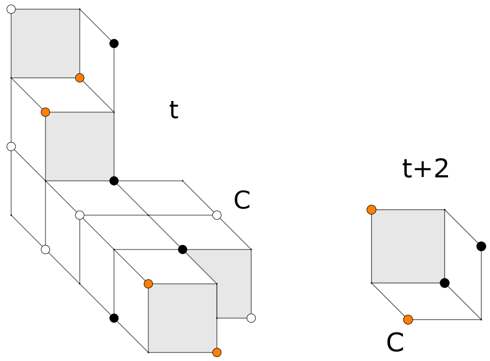

Figure 3: Change in direction of GI by the collision with GII. Left: before the collision, right: after the collsion. The cells labelled C in both configurations are the same.

to the following;

$$\begin{aligned} F(0,0,2) &= F(0,1,2) = F(1,4,0) = F(1,4,1) = \\ F(1,5,0) &= F(1,8,4) = F(1,12,0) = 1, \\ F(1,2,0) &= F(1,2,1) = F(2,2,2) = F(2,2,3) = \\ F(2,3,2) &= F(2,4,0) = F(2,4,1) = F(2,5,0) = \\ F(2,8,4) &= F(2,12,0) = 2. \end{aligned} \quad (3)$$

Entries not defined above are set to zero. Rules (3) are chosen for its consistency with various gliders and other stationary patterns mentioned below. [1]

Operations on Flying Bit

Figure 3 illustrates that a GI undergoes a right-angle turn following a collision with another glider type named GII (Ninagawa, 2018), itself generated by the collision between two GIs. After the collision, the GII vanishes.

The collision of two GI yields a novel glider type termed GIV, as illustrated in Figure 4. Considering GIV glider as a flying bit 1, the process shown in Figure 4 denotes the set of flying bit 0 to 1.

Several stationary patterns exist within (3). Figure 5's upper section displays a GIV passing leftward near a stationary pattern termed SI_0, located in the top left corner. Four steps later (bottom of Figure 5), the GIV transforms into a GI, while SI_0 remains intact. This process is regarded as the reset of flying bit 1 to 0.

Conclusions

We have developed the FCCA rule set (3) being inspired by the idea of excitable media. We have achieved constructing flying bit 0 (Figure 2), turning it at right angles (Figure 3), converting it into flying bit 1 (Figure 4), and resetting it (Figure 5). As a future plan, we are trying to construct logic gates using the flying bit.

[1] A FCCA simulator that runs on browser is available at github.com/ShigeruNinagawa438/FCCA3).

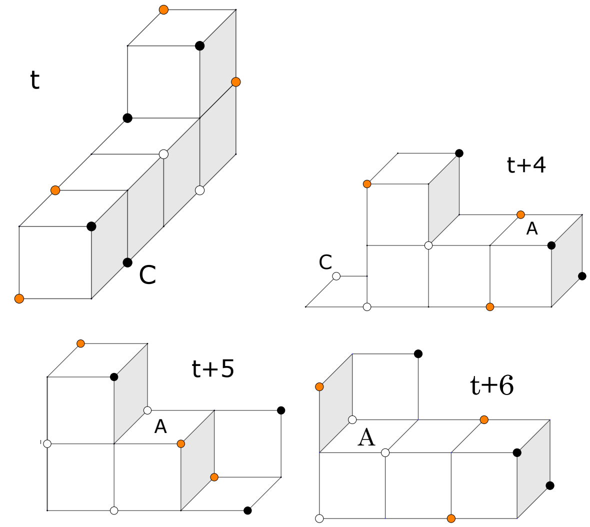

Figure 4: Creation of GIV by the collision of two GIs. Time t: before the collision, time $t+4 \sim t+6$: the creation of GIV proceeding to the right. The cells labelled 'C' and the face labelled 'A' in both configurations are the same.

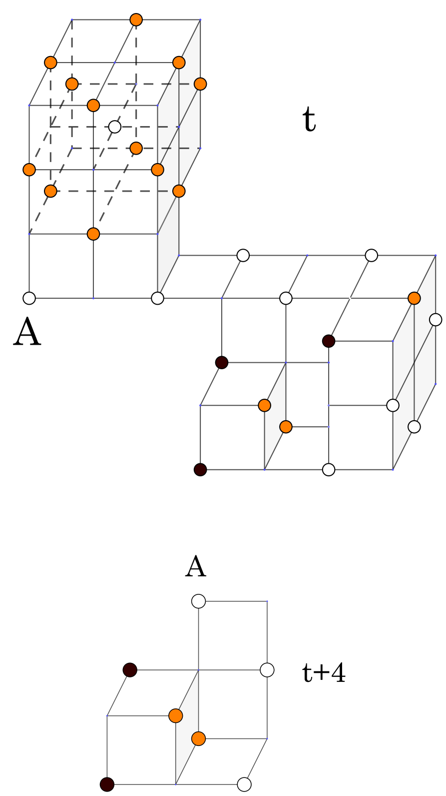

Figure 5: Reset process of flying bit 1 to 0 by passing near a stationary pattern SI_0. Top: Configuration before the passage (time t), bottom: after the passage (time $t+4$). The cells labelled 'A' in both configurations are the same.

References

Adamatzky, A. (1998). Universal dynamical computation in multidimensional excitable lattices. *Int. J. Theo. Phys.*, 37(12):3069–3108.

Adamatzky, A. (2001). *Computing in Nonlinear Media and Automata Collectives*. IoP Publishing, London.

Adamatzky, A. (2013). *Reaction-Diffusion Automata: Phenomenology, Localisations, Computation*. Springer, Heidelberg.

Bays, C. (1987a). Candidates for the Game of Life in three dimensions. *Complex Systems*, 1:373–400.

Bays, C. (1987b). Patterns for simple cellular automata in a universe of dense-packed spheres. *Complex Systems*, 1:853–875.

Conway, J. H. and Sloane, N. J. A. (1993). *Sphere Packings, Lattices and Groups 2nd. ed.* Springer, New York.

Gerhardt, M. and Schuster, H. (1989). A cellular automaton describing the formation of spatially ordered structures in chemical systems. *Physica D*, 36:209–221.

Gerhardt, M., Schuster, H., and Tyson, J. J. (1990a). A cellular automaton model of excitable media II. curvature, dispersion, rotating waves and meandering waves. *Physica D*, 46:392–415.

Gerhardt, M., Schuster, H., and Tyson, J. J. (1990b). A cellular automaton model of excitable media III. fitting the Belousov-Zhabotinskii reaction. *Physica D*, 46:416–426.

Gerhardt, M., Schuster, H., and Tyson, J. J. (1990c). A cellular automaton model of excitable media including curvature and dispersion. *Science*, 247:1563–1566.

Greenberg, J. M. and Hastings, S. P. (1978). Spatial patterns for discrete models of diffusion in excitable media. *SIAM J. Apple. Math*, 34(3):515–523.

Markus, M. (1990). Modelling morphogenetic processes in excitable media using novel cellular automata. *Biomed. Biochim. Acta*, 49(8/9):681–696.

Ninagawa, S. (2018). Patterns and their interaction in excitable media on face-centered cubic lattice. In *7th International Conference, TPNC 2018, Dublin, Ireland, December 12–14, 2018, Proceedings*, pages 99–110. Springer.

Ninagawa, S. (2024). Developmental construction of face-centered cubic cellular automata inspired by excitable media. In *Advances in cellular automata (in press)*. Springer.

Preston Jr., K. and Duff, M. J. B. (1984). *Modern Cellular Automata Theory and Applications*. Plenum Press, New York.

Tóth, A., Gáspár, V., and Showalter, K. (1994). Signal transmission in chemical systems: Propagation of chemical waves through capillary tubes. *J. Phys. Chem.*, 98:522–531.

Tóth, A. and Showalter, K. (1995). Logic gates in excitable media. *J. Chem. Phys.*, 103:2058–2066.

Wojtowicz, M. (Accessed on 2023-03-16). Cellular automata rules lexicon. `http://http://www.mirekw.com/ca/rullex_gene.html`.