2017 International Symposium on Nonlinear Theory and Its Applications,
NOLTA2017, Cancun, Mexico, December 4-7, 2017

Polychronization in an Asynchronous Cellular Automaton Model of Spiking Neural Network

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In biological neural networks, action potentials are transmitted through axons with certain delays. Such delays can realize a wide variety of spatio-temporal patterns of action potentials such as polychronization [1]. On the other hand, our group has been developing various biological system models, which has a continuous time and discrete states, e.g.,[2][3],where the models are implemented by asynchronous cellular automata. Features of such models include

- smooth nonlinear vector field by asynchronicity,
- smooth bifurcation structure by asynchronicity, and
- lower hardware cost compared to synchronous models.

In this paper, a network of asynchronous cellular automaton neuron model is investigated. Fig. 1 shows the structure of the network. Each neuron has the following discrete state variables.

$$\text{Membrane Potential} \quad V_i \in \mathbf{Z}_M,$$
$$\text{Recovery variable} \quad U_i \in \mathbf{Z}_N,$$

where $\mathbf{Z}_M = \{0, 1, M-1\}$ and $\mathbf{Z}_N = \{0, 1, N-1\}$. The neuron also has asynchronous clocks $C_{V_i}(t)$ and $C_{U_i}(t)$, which trigger the following asynchronous transitions of the discrete states V_i and U_i of the i-th neuron, respectively.

$$\text{If } C_{V_i}(t) = 1, \quad \text{then } V_i := V_i + F(V_i, U_i),$$
$$\text{If } Y_j(t) = 1, \quad \text{then } V_i := V_i + W_{ij},$$
$$\text{If } C_{U_i}(t) = 1, \quad \text{then } U_i := U_i + G(V_i, U_i),$$

where := represents instantaneous state transition and $W_{ij} \in \{0, 1, \cdots, L\}$ represents synaptic weight form the j-th neuron to the i-th neuron. Also $F \in \{-1, 0, 1\}$ and $G \in \{-1, 0, 1\}$ are discrete functions, which determine the vector field of the neuron. Fig. 2 shows a typical phenomenon of the proposed model. It can be seen that a group of action potentials is evoked by another group of past action potentials and such evokes continue, where such phenomenon is called the polychronization. In the presentation, we will show that our network can exhibit various types of polychronizations. We will also discuss engineering applications of the polychronizations.

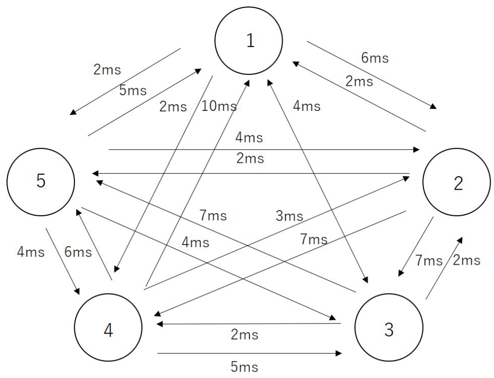

Figure 1: Structure of the network.

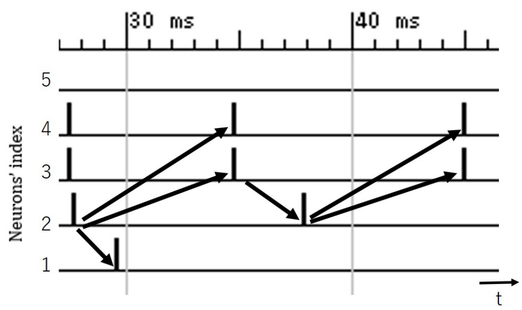

Figure 2: Polychronization of action potentials given by VHDL simulation.

References

[1] E. M. Izhikevich, Polychronization: Computation with Spikes, Neural Computation, vol. 18, pp. 245-248, 2010.

[2] K. Takeda, H. Torikai, A Novel Hardware-Efficient Cochlea Model based on Asynchronous Cellular Automaton Dynamics: Theoretical Analysis and FPGA Implementation, IEEE Transactions on Circuits and Systems II: Express Briefs (accepted).

[3] T. Naka, H. Torikai, Asynchronous CA spiking neural network and its classification function, Proc. TJCAS, p. 51, 2017.