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Neural Firing of Coupled Izhikevich Neurons with Bug Neuron

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1. Introduction

Myriad of neurons exist in our brain. Information processing and transmission are performed by neural firing. In analyzing the neural firing, it is essential to consider the cycle of neural firing and firing pattern.

In this study, we focus on the influence that the neuron including a bug has on others neurons. Furthermore, we investigate the phenomena when the neurons are coupled as the ladder network. By carrying out computer simulations, the propagation of the bug is confirmed.

2. System model

The Izhikevich neuron model [1] is presented that reproduces spiking and bursting behavior of known types of cortical neurons as shown in Fig. 1.

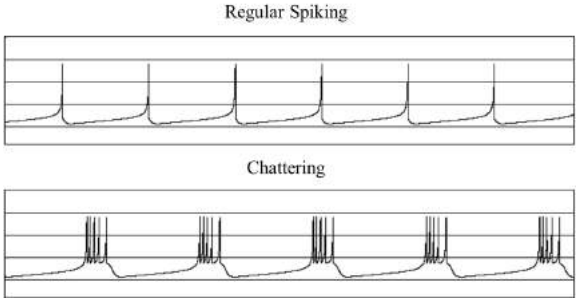

Figure 1: Examples of neural firing patterns.

In addition, this model is described by the following equations:

$$\begin{cases} \dot{v} = 0.04v^2 + 5v + 140 - u + I \\ \dot{u} = a(bv - u), \end{cases} \tag{1}$$

with the auxiliary after-spike resetting
if $v \geq 30$mv, then

$$\begin{cases} v \leftarrow c \\ u \leftarrow u + d. \end{cases} \tag{2}$$

Here, v and u are dimensionless variables, and a, b, c and d are dimensionless parameters and $\dot{} = d/dt$, where t represents the time. The variable v represents the membrane potential of the neuron and u represents a membrane recovery variable. In this study, we consider ladder network using Izhikevich neuron model as shown in Fig. 2. We set the neuron including a bug to neuron 2. These neurons are coupled by a gap junction and they are fixed as same type of neuron. We investigate two patterns which are described as follows:

- Pattern 1 : Regular Spiking (RS).
- Pattern 2 : Chattering (CH).

Furthermore, we investigate the effect of neurons when the coupling strengths δ between neurons are fixed as same value. Range of δ is set from 0 to 0.8, the bug occurs at the rate of 10 - 50%. The bug is defined as the phenomenon that causes abnormal at the time of the neural firing. In particular, neuron including a bug does not fire even when the threshold value is exceeded.

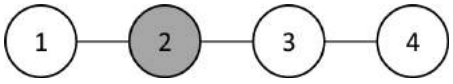

Figure 2: Model of the ladder network.

3. Simulation results

Figure 3 shows some of simulation results. As some simulation results, propagation of the bug is observed. In the case of pattern 1, the bug is propagated to all neurons on the network. However, the bug is propagated only neurons adjacent to the bug neuron for pattern 2.

In addition, we observed various firing patterns. Twice firing per one cycle is observed as one case.

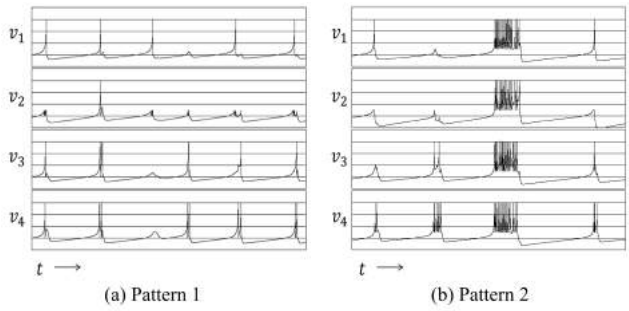

Figure 3: Time waveforms when we set the coupling strength $\delta = 0.8$ and bug rate = 50%.

4. Conclusions

In this study, we have investigated the effect of neuron including a bug on the network. As some computer simulations, we have confirmed the propagation of the bug in a ladder network. In addition, the firing patterns of each neurons are changed by coupling the neuron including a bug.

In our future works, we would like to simulate for large scale and investigate by the combination of other firing patterns.

Reference

[1] Eugene M. Izhikevich, "Simple Model of Spiking Neurons," IEEE TRANSACTIONS ON NEURAL NETWORKS, VOL. 14, NO. 6, NOVEMBER 2003.