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Synchronization Phenomena of Izhikevich Neuron Model as a Ladder Network

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1. Introduction

Myriad of neurons exist in our brain. Information processing and transmission are performed by neural firing. It becomes clear that the pattern of neural firing changes according to the situation. In this study, we investigate synchronization phenomena of Izhikevich neuron model as a ladder network. Furthermore, we observe the effect of neurons with different firing pattern.

2. System model

The Izhikevich neuron model is presented that reproduces spiking and bursting behavior of known types of cortical neurons. 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 a ladder network using Izhikevich neuron model as shown in Fig. 1. The neurons in a ladder network are coupled by a gap junction and the coupling strength between neurons represents δ.

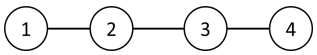

Figure 1: Model of the ladder network.

The patterns of neural firing are described as follows:

- Neuron 1 is fixed as the regular spiking (RS).
- Neuron 2 and 3 are fixed as the intrinsically bursting (IB).
- Neuron 4 is fixed the chattering (CH).

Furthermore, we investigate the effect of neurons when the coupling strengths between neurons are fixed as same value.

3. Simulation results

Figure 2 shows the attractor of four neurons. Waveforms of four neurons is shown in Fig. 3. The parameter of coupling strengths are fixed as $\delta = 1.1$. The attractors and waveforms are observed in the pattern of each of neural firing. By coupling the neurons with different firing pattern, the firing patterns of each neuron are changed. As these simulation results, synchronization phenomena between neurons and periodic solutions are observed in our proposed network. In addition, we confirm that neuron 1, 2 and 3 cause burst firing by influencing the neuron 4.

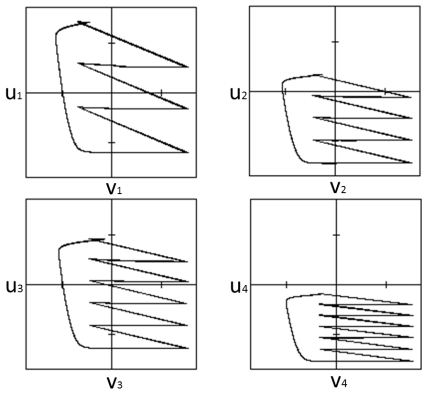

Figure 2: Attractors of four neurons.

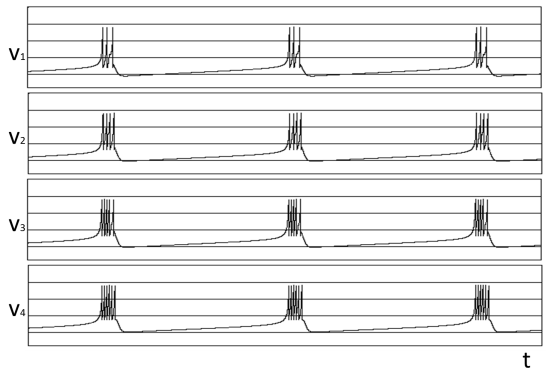

Figure 3: Waveforms of four neurons.

4. Conclusions

We have investigated synchronization phenomena of Izhikevich neuron model as a ladder network. By carrying out computer simulations, we have confirmed the synchronization. In addition, we have observed periodic solutions. In our future works, we would like to simulate for large scale and investigate by the combination of other firing patterns.