Adaptive information processing by the use of neural-network dynamics

Satoshi Ohta

School of Knowledge Science,
Japan Advanced Institute of Science and Technology
March 2001

Keywords: spiking neuron model, spike timing dependent synaptic plasticity

In recent years, many anatomical and physiological findings indicate that spike timing may play an important role in the information processing of the neural networks in the brain. For example, it is found obviously that temporal synchronized firing timing between single neurons in the frontal cortex changes dynamically depending on the context of behaviors, although, for these behaviors, these two neurons do not change firing rates. For another example, the synaptic weight is modified dynamically according to the relative timing of pre- and post-synaptic action potentials.

I have tried to clearify, through this research, the adaptive information processing, by which higher organism determinates his various behaviors to various environments. In order to elucidate information processing mechanism on neural networks in the brain, I researched the neural network dynamics, using an artificial spiking neural network that is constructed by considering anatomical and physiological findings, mounting the spiking neural network on computer, and simulating information processing by calculating spikes location and firing timings of neurons on network. There are many spiking type neuron models. In the case of this research, integrate and fire neuron model was chosen as a neuron model. This neuron model has virtual connectivity that constructs network structure. When one neuron model receives a spike from another neuron, the internal potential increases rapidly shift up and falls slowly at next moment. When many spikes arrive one neuron from others, every influence of arrival spikes is added linearly. If this voltage reaches some threshold, spiking neuron model creates a spike, fire, and transmits it to the other dendrites of other neurons through a virtual axon. In this neural network model, synaptic weight modified dynamically. Concretely, when a presynaptic neuron contributes to the postsynaptic neuron's fire, the synaptic weights between there is largely. On the other hand, if a spike is received within absolute refractory period that is micro seconds after firing, the synaptic weights is decreased. As a result, spiking neuron model has the rule of synaptic weights depending on pre- and post-synaptic activities.

I used the network model explained above consists of 16-20 neurons. About 80% of the neurons were excitatory, and the rest (about 20%) were inhibitory. Initial values of synaptic weights were selected randomly. The same spatiotemporal pattern for 1 sec that spikes time series was repeatedly input. The spatiotemporal pattern observed was generated by Poisson process. Under these experiment conditions, I observe spatiotemporal patterns, synaptic weights, and internal voltage at every neuron on network, the return maps in the state space of internal activity of neurons, and an attractor's structure.

As a result, although the network structure, all parameter values of synaptic weights, and synaptic initial values are the same, the various periodic or aperiodic spatiotemporal patterns of outputs on the input patterns that are created by different random seed. Here, I assume that the input spatiotemporal pattern has period 1, and this input is repeatedly input for every second. In order to investigate these periodic phenomena, I focused on weight time series at each synapses, internal voltage time series in each neuron on the network. If the dynamics had periodic outputs of spatiotemporal pattern, weight time series drew periodic and it was checked by the use of return map that is constructed by sampling internal voltage states of some neurons moved cyclic some state. On the others, if the dynamics had aperiodic output patterns, weight time series drew aperiodic and internal voltage state moved acyclic some state. In aperiodic cases, the attractor has dense structure. Attractor is reconstructed by sampling from internal voltage time series of neurons.

Considering these results, it is showed that the spiking neural network model prepared in this research can create various periodic dynamics according to input spatiotemporal patterns, not depending on initial network structure, initial value of the synaptic weights. Moreover, it may be considered that the control information changes the periodical dynamics of neural network is packaged inner input spike spatiotemporal patterns.

This research showed that one or more periodic dynamics were produced from the same initial structure and the renewal rule of synaptic weights, using different input spatiotemporal patterns. And the dynamics that has periodic time series may explain of the adaptive information processing in the brain. However, we do not know how parameters should be adjusted in order to carry out arbitrary periodic dynamics. I think that mathematical study on how arbitrary periodic dynamics are induced is needed.