A Rhythm Perception Model by Neural Rhythm Generators

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Abstract

It is known that dynamics of mutual inhibition neural networks produces constant rhythm pattern with step inputs. Therefore, these neurons are called "Neural Rhythm Generators." A rhythm perception model by neural rhythm generators which consists of 2 neurons is presented, and the relation between input beat and rhythm perception is shown by computer simulations.

1 Introduction

In living body, we can see periodic rhythmic phenomena such as heart beat, breathing and walking. In these phenomena, some of which cycles are relatively short are thought to be controlled by nervous system. For example, bipedal locomotion model by dynamics of neural networks has been presented [Taga, 1991].

When we listen to the rhythm pattern in music, our actual perception system may be spread from high level information processing in the cerebrum to relatively low level processing of neural networks. But if we limit rhythm pattern to primitive beat without melody use harmony, the perception system can be thought to be processed only in the neural networks.

It is known that dynamics of mutual inhibition neural networks produces constant rhythm pattern under some conditions with step inputs. Therefore these neurons are called "Neural Rhythm Generators" [Matsui, 1985, Matsui, 1987].

This paper presents a basic model of musical rhythm listening by "Neural Rhythm Generators," and shows some computer simulation results.

2 Neural Rhythm Generators

Rhythm perception model I adopt is "dynamics of mutual inhibition neural networks." As a model of individual neuron, I adopt a continuous-time, continuous-variable neuron model, since I think it essential to treat dynamics of neurons when we think of rhythm, which is dynamical in itself.

The most traditional continuous-time continuous-variable neuron model is shown as $\tau \frac{du}{dt} + u = g - \theta$. But if step input is inputted into this model, the output rises monotonously and finally reaches a constant value. On the other hand, real neurons' output rises and then falls into a constant value. This falling is known as "adaptation effect." I adopt the model shown in [Matsui, 1985] because Matsuo's model has this "adaptation effect."

A mutual inhibition neural network consisting of $n$ neurons of Matsuo's model is presented by:

$$\tau_i \frac{du_i}{dt} + u_i = - \sum_{j=1}^{n} w_{ij} y_j + s_i - \beta f_i$$

$$y_i = g(s_i)$$

$$g(u) = \max(0, u)$$

where $T_i$ is a time constant of the neuron, $u_i$ a membrane potential of the $i$-th neuron body, $w_{ij}$ a weight of inhibitory synaptic connection from the $j$-th neuron to the $i$-th neuron, $y_j$ a firing rate or output of the neuron, $s_i$ an impulse rate of the input to the $i$-th neuron, $T_i$ the time constant that specifies the time lag of the adaptation effect, $\beta$ the degree of fatigue or adaptation. $s_i$ is positive, so $-\beta s_i$ means mutual inhibitory connection.

If step inputs are inputted into both neurons under some conditions of parameters, these neurons fire by turns, namely produce constant rhythm pattern. Mutual inhibition neural network that produces these kinds of rhythm pattern is called "Neural Rhythm Generators."

3 Simulations and Results

The simplest model of Neural Rhythm Generators consists of 2 neurons. Using this simplest model, a rhythm perception model (Figure 1) is designed, in

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which Neuron1's "Best Input" plays a role to bear the outer world, which means it receives beat impulses. The outputs of Neuron1 and Neuron2 are thought to be the dynamics of rhythm perception.

![Diagram of neuron model](image)

Figure 1: rhythm perception model of 2 neurons

Two computer simulations were taken under the following conditions:

1. Input beat pattern
2. Input beat pattern, but one beat is bigger than the others

In each case, several kinds of frequencies are tested, and step inputs are inputted into both 2 neurons.

In the first experiment, beats which are $4/3$ times as big as step input are inputted into Neuron1. Beat cycles are 30, 40, 50, and the time width of beat is 5 (cycle ≈ 30), 10 (cycle ≈ 40, 50). Six beats are inputted from time 100. As seen in Figure 2, it is shown that the output rhythm naturally follows the frequency of the input beats within a limited area even if the input beat frequency is not the system's frequency. It also shows that the Neuron2 plays a role of upbeat to the input downbeat. Walts model will be designed by 3 neurons model. The situation is almost the same if cycle is other than 30.

In the second experiment, the conditions are almost the same as the first experiment, but one beat is bigger (double) than the others. As seen in Figure 3, it is shown that the system is naturally affected so that the cycle of both neurons becomes longer when bigger impulse comes. It can be interpreted that even if one feels periodic rhythm by oneself when one beat in input rhythm is bigger than the others, one's rhythm perception is objectively affected, perturbed.

4 Conclusion

A rhythm perception model by 2 neurons neural rhythm generators is presented. It is shown that the rhythm perception system naturally follows the frequency of the input beats, and is also shown that the system is affected so that its rhythm perception cycle becomes longer when bigger beat impulse comes. Followable frequency limitation will be expanded if the network consists of many neurons of which time constant are slightly different.

References

