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Neural Coding Model Using the Morphoelectrotonic Transform Theory

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It is believed that the color and the shape movement etc. of objects are expressed with time series of neuron spikes in the brain. We do not have any answer to realize the process, “What kind of neuron dynamics works and is able to express the processes?” To solve this problem, we need at least to study the neural coding where information is expressed by the spike sequence.

In this research, it introduces the neural coding that uses the theory of morphoelectorotonic transform. The morphoelectorotonic transform is a theory based on the experiment on neurophysiology, and the neuron circuit can change dynamically depending on this coding model. Moreover, a simulation model that solved the binding problem to use this coding model is constructed, and significant of coding is verified.

1. Introduction

The neuron receives the input from a lot of other neurons, and has a precise form that can integrate them. It is necessary to consider transmission by the form of the neuron so far though there were a lot of models that values the sum total and the timing of the firing activity.

In this research, to change the neuron group dynamically in proportion to the distance, it proposes the neural coding model that uses the theory of the morphoelectorotonic transform [1] [2] based on neurophysiology. And this morphoelectorotonic transform has succeeded to the theory of dynamical cell assembly [3]. In addition, it simulates this coding model that is applied to the binding problem [4] [5] of the visual information processing. It is assumed that the biding problem is a good example that clarifies the neural coding and the computation theory of the vision.

The behavior of neuron by this simulation is verified, and it is shown that the significance of the morphoelectorotonic transform in the neural coding.

2. The Morphoelectrotonic Transform

When a potential injected into a membrane exceeds a constant threshold, the morphoelectrotonic potential corresponding to the input stimulation is generated. For example, this morphoelectrotonic potential is observed in neocortical pyramidal neuron dendrites of rat's olfactory cortex [5] [6]. The potential decreases in proportion to the length of neural axon and dendrite by being caused with the resistance of the membrane and the cytoplasm. The morphoelectorotonic transform measures a distance between two neurons using an attenuation rate of a current that flows between them. A morphoelectorotonic transform is expressed by a distance which is calculated by using the amount of the morphoelectorotonic potential and is decided when it decreases to 1/e (e: common logarithm).

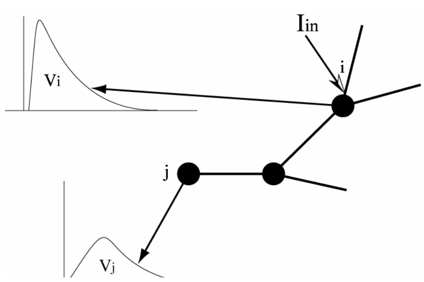

Fig1 Dynamic features of voltage V_i and attenuating voltage V_j when stimulation i is input [1]

2.1 Attenuation Function of Voltage

The attenuation function of the voltage in membrane [1] shows generally the morphoelectrotonic transform in the dendrite with a divergence structure. The morphoelectrotonic transform does not depend on an actual size of the neuron, but depends on a distance of two points of the neurons where stimulations to the neurons are observed [1].

Therefore this attenuation function can be expressed with a logarithm of the

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attenuation of the voltage at the position where the stimulation current is input and measured. Figure 1 shows the dendrite and voltages and an impulse stimulation, I_{in}, which is inputted at the position of i and is measured at the position of j. Attenuation function L_{ij} (Exp.1) is a logarithmic function of the value in which the voltage V_i at the input position is divided by the voltage V_j at the measured position.

$$L_{ij} = \log\left(\frac{V_i}{V_j}\right) \qquad (1)$$

A simulation system is constructed to shows synchronization or asynchronous dynamics according to the distance between neurons by using L_{ij} which shows an electric distance. In this research, the difference of voltages between the input and the measurement is assumed to be a difference of the probability density of the pulse generation, and an intercellular distance is assumed to be intervals of the pulses which flow between the neurons.

3. Binding Problem

A binding problem in visual information processing is that an integration of different modalities in visual cortex is hard to solve for us. The modalities of color or shape of the object are processed in separate fields in the brain. In the upper part of Figure 2, a red triangle object is processed by the neuron group that reacts to "red" in the color recognition field and "triangle" in the shape recognition field. A blue circle is similarly processed by the blue neuron group and the circle neuron group. But if two objects are processed at the same time, the problem is caused. When a red triangle and a blue circle are

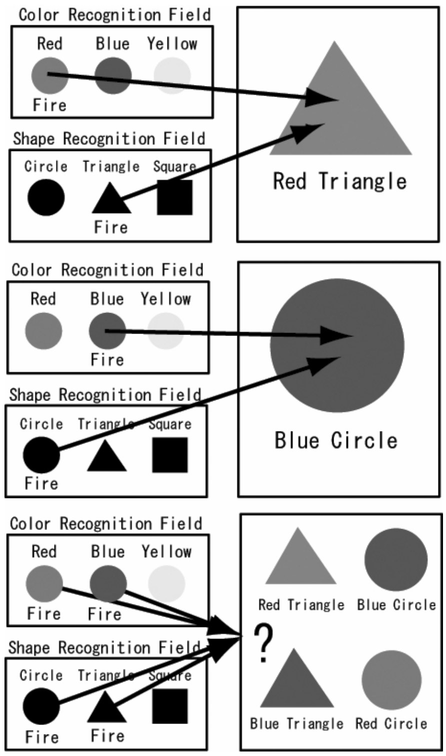

Fig2 Schema of Binding Problem

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processed, each neuron group reacts to "red" and "blue" in the color recognition field, and "circle" and "triangle" in the shape recognition field in Figure 2 lower. Therefore four kinds of "red triangle, red circle, and blue triangle, blue circle" are supposed as the result of these combinations. The binding problem is to find a way how a red triangle and a blue circle object can be extracted from these combinations.

4. Binding Simulator

This chapter explains an algorithm in the Binding Simulator by using a red triangle and a blue circle shown in Chapter 3 as a simple example. The input pulse sequence is such a sequence shown in Figure 3. These sequences how that a red triangle is expressed with d d-t-c-s-h-x and a blue circle with p-h-l-b-m-d . Then the sequences are processed in the color recognition field and the shape recognition field respectively. When a sequence of red triangle is processed, the sequence with the intervals among d, c, and h has a route of cell 5-1-4 in Fig.4. The simulator finds that the sequence corresponds to "red" because this route is recognized as a modality of "red" in the color recognition field. And when the blue circle sequence is processed, the sequence shows a modality of "blue" with the route of cell 5-9-8. In the shape recognition field, it is recognized that there are a modality of "triangle" from the red triangle sequence and a modality of "circle" from the blue circle sequence.

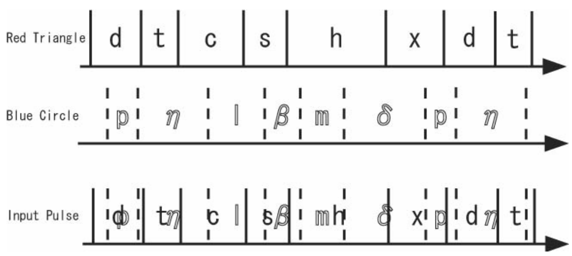

Fig3 Input Pulse Sequence

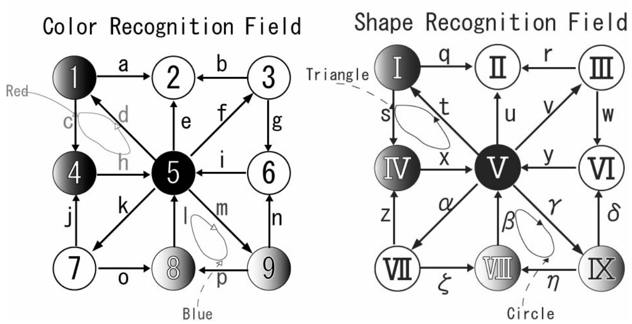

Fig4 Color Recognition Field and Shape Recognition Field

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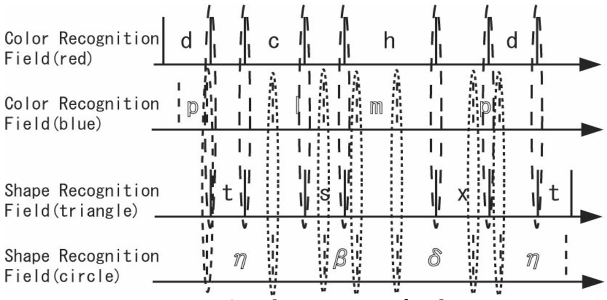

Fig5 Synchronization of pulse

Next the coincidence detector [7] is utilized to detect synchronization of the pulses. The modalities can be bound by synchronizing these sequences. The sequences of modalities of "red" and "triangle", "blue" and "circle" have the same interval respectively as shown in Fig.5. When the modalities of the object are recognized, an intercellular morphoelectrotonic transform is computed from the sequence.

The pulse sequences of each object are shown by the pulse density in Figure 6. The peak values V_{rt} and V_{bc} of these densities is supposed to be voltages of the neuron group. These voltages are applied to the attenuation function of the voltage explained by section 2.1, and the morphoelectrotonic transform of the neuron group is computed that shows a red triangle and a blue circle. The neuron circuit is dynamically changed by reflecting this morphoelectrotonic transform in the intercellular time interval. As a result, increase of the number of binding problems of modalities can be avoided.

4.1 Simulation result

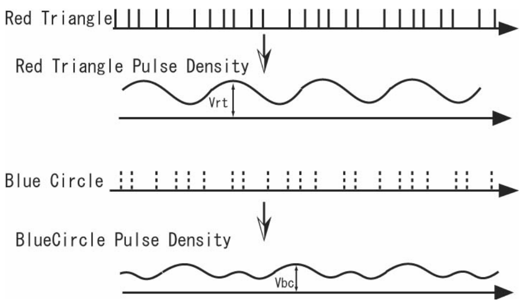

Fig6 Red Triangle and Blue Circle Pulse

This neural coding model was simulated by using the binding problem with "red, blue, and yellow" as color modalities and "circle, triangle, and square" as shape modalities. In a simulation, combination of two objects was classified into 1.different color and shape objects, 2.same color and different shape objects, and 3.different color and same shape objects. In the first category, 13 cases of the combination were bound and the morphoelectrotonic transform was able to be computed. In the second category, 4 cases of combination and 8 cases in the third were bound and morphoelectrotonic transform was able to be computed. The number of combination of the binding was

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not increased on 18 cells because intervals of the neuron circuit had been changed by the morphoelectrotonic transform.

5. Conclusion

In this research, significance of the morphoelectrotonic transform was verified by modeling the theory and simulating the binding problems. A dynamic neuron circuit which was synchronized or non-synchronized among neurons in proportion to the distance was constructed by using the morphoelectrotonic transform. In addition, the number of combination in the binding problems was able to be increased.

We would like to continue this simulation in the future, and to check how the distance changes in many types of the neural circuits. And it seems interesting to study how each modalities can be classified when modalities of the object are increased.

Because the distance between neurons is important in a neural coding, the morphoelectrotonic transform seems to include other important factors that influence such a coding. It is important to consider new parameters such as a frequency of active potential in the morphoelectrotonic transform.

References

1. AM. Zador, H. Agmon-Snir and I. Segev: The morphoelectrotonic transform: A Graphical Approach to Dendritic Function. Neuroscience, 15, 1669-1682 (1995)

2. WR. Chen, J. Midtgaard, GM. Shepherd: Forward and Backward Propagation of Dendritic Impulses and Their Synaptic Control in Mitral Cells. Science, 278, 463-467 (1997)

3. H. Fujii, H. Ito, K. Aihara, N. Ichinose, and M. Tsukada: Dynamical Cell Assembly Hypothesis - Theoretical Possibility of Spatio-Temporal Coding in the Cortex. Neural Networks, 9, 1303-1350 (1996)

4. Von der Malsburg: Binding in models of perception and brain function. Neurobiology, 5, 520–526 (1995)

5. A.R. Damasio: The brain binds entities and events by multiregional activation from convergence zones. Neural Computation, 1, 123-132 (1989)

6. G. Stuart, N. Spruston: Determinants of voltage attenuation in neocortical pyramidal neuron dendrites. Neuroscience, 18, 3501-3510 (1998)

7. M. Abeles: Role of the Cortical Neuron: Integrator or Coincidence Detector. Israel Journal of Medical Sciences, 18, 83-92 (1982)

8. P. Dayan and L.F. Abbott: Theoretical neuroscience: computational and mathematical modeling of neural systems. Cambridge, Mass. MIT Press, (c2001)