Neuronal cell model with the synaptic local variables, and integrating neural network modules with chaos.

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Abstract

Information processing of the brain can be defined as the firing dynamics on neural network. It is a processing style acquired by the evolution of animals to efficiently execute a computation for survival. In this thesis, several features of information processing by neural network are made clear with the help of biochemical and the anatomical restrictions.

First, a neuronal cell model with the synaptic local variables based on the synaptic buffering due to Ca^{2+} density and a bi-directional synaptic learning rule are constructed to explain the mechanism of information transmission on neural network.

In our neuronal cell model, the intra-cellular dynamics are given according to the synaptic local bufferings and their interaction. Explicit description of the intra-cellular dynamics provides a framework to consider the role of various dendritic structures for information processing. The synaptic learning rule is given based on the biochemical hypothesis for the synaptic potentiation and depression with Ca^{2+}/calumodulin-dependent protein kinase II as central substance. Synaptic localization of the proposed learning rule clearly separates the neural firing, that is the primary representation for neuronal information, and the plastic process of the synapses. Several phenomena at the neuronal cell can be simply explained by our models, for instance the cooperative synapse plasticities and the back-propagating action potentials. In this thesis, we indicate the synaptic potentiation and depression at cerebellar Purkinje cells as an example for the temporally dependent synaptic plasticity which are explained on our neuronal cell model.

Functional localization with the module structure such as functional column or sensory area exists at the nerves system. On the other hand, these modules behave as a single information processing system as the brain.

In the second part of this thesis, the chaotic neural network model (Nozawa model) is expanded into module structure. Moreover, the relation between strength of the intermodule connections and the pattern recalling property at a neural network module is investigated. Consequently, it was shown that the chaotic neural network models could be functionally integrated without an external controller or algorithm. Furthermore, the connection between neural network models creates novelty internal representations besides the embedded states as a memory. This result suggests that the chaotic dynamics as an internal mechanism of the neural network works effectively in regard to how the brain integrates a lot of sensory information.

keywords: Neuronal cell model, Ca^{2+} buffering, Synapse plasticity, Modularity of neuronal structure, Chaos