論文の内容の要旨

Mathematical Modeling of Meso-Scale Nonlinear Dynamics in the Brain
（脳におけるメゾスケール非線形ダイナミクスの数理モデル化）

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（本文）Our understanding of the brain has been greatly advanced in the last tens of years. However, we have not yet come to any sufficient explanation of how our mind and consciousness arise from the electrical signal transmission between a huge number of neurons. To solve this daunting problem, as many researchers believe, we need to understand the brain through its hierarchy of different scales: micro-scale, meso-scale, and macro-scale.

The meso-scale level corresponds to the network level, and the population dynamics emerging from a number of neurons' interaction is of our interest. There is no concrete definition of the term `meso-scale', especially with respect to the number of neurons. However, increasingly many neurons recently become both measurable by experiments and computable by numerical simulations. Thus, we can deal with much more neurons than before in investigating meso-scale brain phenomena. In addition, understanding of the brain at the meso-scale level is crucially important because it links the micro-scale level and the macro-scale level.

In this thesis, we investigate brain phenomena at the meso-scale level by using both large-scale neural networks and coarse-grained models of neurodynamics. Specifically, we use the following mathematical models: (1) large-scale chaotic neural networks (CNNs) with more than one million units, (2) a coarse-grained model based on the Potts model, (3) large-scale modular neural networks, each module of which consists of a Hopfield network and a multilayered perceptron, and (4) a meso-scale mathematical model that describes dynamical inter-region couplings at the viewpoint of the dynamical systems theory. These mathematical models are related to each other and play complementary roles to investigate meso-scale brain phenomena from multiple points of view.

Our main contributions are as follows. (1) We perform simulations involving one million units for the first time in the case of the CNN model. In the simulations, we find that chaotic itinerancy can occur in such a high-dimensional system. (2) We develop certain visualization methods for the large-scale CNNs. (3) We report traveling waves in neural networks for the first time in the case of the associative memory model. We reproduce these waves qualitatively by using a modified Potts model, which has a negative self-feedback mechanism. (4) We consider an extension of the associative memory model, which has a memory relation network structure. This idea is actually realized numerically. (5) We consider `computation' based on the pattern representation, which may be new. Stochastic resonance is also observed in the computation. (6) We propose a new interpretation of dynamical inter-region couplings such as binding. To explain our hypothesis, we develop a new mathematical model.

The above-mentioned contributions (and also others discussed in the thesis) are expected to be significant for researches on the meso-scale brain phenomena, which will meet great advances in the near future based on the progress of large-scale simulations and multineuron recordings. In addition, we believe that our works ultimately contribute to the hierarchical understanding of the brain.