論文の内容の要旨

論文題目 Flexible Information Processing with Nonlinear Dynamics in Neural Networks

（ニューラルネットワークにおける非線形ダイナミクスを用いた柔軟的な情報処理）

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The ability to process information in a flexible manner is crucial for an animal to adapt to the ever-changing environment. Although intensive efforts have been made to understand the neural mechanisms behind flexible information processing, little is known about how this is achieved in the brain. In this thesis, we explore several neural mechanisms that may contribute to this ability, through theoretical, as well as experimental studies.

Specifically, in the first study, we investigate the dynamics and stability of associative memory, by incorporating sparse coding and nonlinear, short-term synaptic dynamics. Using a mean field technique, we obtain the detailed bifurcation structure in stability and investigate how various dynamics depend on the sparseness of memory patterns, the time constants of synaptic dynamics and the strength of a negative feedback to the associative memory network. When the memory patterns become sparse, the appearance of spurious states is shown to hamper the performance of memory retrieval. However, we demonstrate that this can be compensated

by applying an appropriate negative feedback. Furthermore, the oscillatory states induced by the short-term synaptic dynamics are found to depend on the sparseness of memory patterns. These results suggest how the encoding and synaptic properties affect the information storage in neural networks.

In the second study, we analyze the change of dynamics in random neural networks under the framework of reservoir computing. In particular, we focus on the influence of the statistical properties of external input. Using a mean field model and numerical methods, we obtain the critical points where the transition between the fixed-point state and the chaotic state occurs. In addition, we show that the statistical properties other than the first two moments of the external input have only inferior effect on the dynamics. The results can be used to design reservoirs in modeling and applications.

In the third study, we analyze data recorded from the prefrontal cortex of monkeys during a working memory task. The task requires the monkey to perform logical computation which associates the outcome of each trial with a visual cue in a flexible way depending on the implicitly given context. We demonstrate that the information processing is underlain by a dynamical representational switching from the context to the behavioral relevant information. Based on our observations, we hypothesize that the prefrontal cortex actively maintains and integrates task-relevant information by separated neural populations, and propose a neural network model in which the neural populations are organized through feedforward, as well as recurrent structures. We show that this model can qualitatively reproduce the results from recorded data by using simulations with noisy integrate-and-fire neurons. Our results suggest that the feedforward and

recurrent structures in the prefrontal cortex are crucial for the flexible information processing in the prefrontal cortex.

Collectively, our studies provide an insight into how various neural mechanisms contribute to the flexible information processing in neural networks.