2005 International Symposium on Nonlinear
Theory and its Applications (NOLTA2005)
Bruges, Belgium, October 18-21, 2005

Modelling of Nonlinear Dynamics in Biological Systems and its Applications to Coding and Processing of Information

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Abstract—In this talk, I review our study on modelling of nonlinear spatio-temporal dynamics in biological systems, especially in the brain and its possible applications to coding and processing of information such as fractal coding in a chaotic neural network and dual coding with both population rates and synchronous firing.

1. Introduction

Generally speaking, biological systems are highly nonlinear and dynamical. In particular, the brain is a typical example of an existing complex system with structural and dynamical complexity and with superior functions. In this talk, I introduce two examples of nonlinear models related to coding and processing of information in the brain, the first from the viewpoint of chaos engineering [1, 2] and the second from a more neuroscientific viewpoint.

2. A Chaotic Neural Network and Fractal Coding

The concept of deterministic chaos has been greatly influencing not only science but also engineering. The influence on enginering has created a field of Chaos Engineering [1, 2]. Among many applications of chaos engineering, parallel distributed processing with chaotic dynamics is our primary concern. The chaotic computing is based upon models of chaotic neural networks [3] composed of chaotic neurons that are derived on the basis of neural chaos observed in electrophysiological experiments with squid giant axons [4, 5] and in numerical experiments with the nerve equations [6]. It is shown that the chaotic neurodynamics [7] is useful in such information processing as dynamical association [8, 9] and combinatorial optimization [10, 11] like TSP and QAP, and can be implemented by analog IC chips [12]. Moreover, with respect to information coding, fractal encoding of time series data into a strange attractor in a state space is realized by a simple model of a chaotic neural network [13].

3. A Dual Coding Hypothesis with Population Rates and Synchronous Firing

The second topic is more neuroscientific modelling of biological neural networks. It is widely accepted that action potentials or neuronal spikes are information carriers in the brain. How action potentials actually encode information, however, is still an ongoing issue. Two main paradigms of neural coding are population firing-rate coding and spatio-temporal spike coding. On the contrary to the hot issue on rate coding vs. temporal coding, it can be shown by a simple neural network model, that the two coding schemes are not necessarily alternative but can be utilized dually depending on intensity of background noise, shared connectivity, and heterogeneity [14].

Moreover, recent discoveries on depolarizing GABA actions and spike timing dependent plasticity are also closely related to the neural coding problem [15–17].

4. Discussion

Recent progress in nonlinear systems analysis has made possible mathematical modelling of complex phenomena both in engineering systems and in natural systems. Among various complex systems in this real world, the brain is a typical example of a complex system, which higher functions are quite interesting even from the viewpoint of engineering.

I will also discuss, if I have time, possible difficulties peculiar to modelling of bilogical systems not only neural networks but also genetic networks [18–21], namely delays, fluctuations, discreteness, stochasticity, and inhomogeneity.

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