Computational Dynamics of Chaotic Neural Networks

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Usually, simple linear threshold elements are adopted as neuron models for the artificial neurocomputing. Although such simple neuron models have been useful to derive some fundamental principles in the artificial neurocomputing , there exists criticism from the viewpoint of physiology that real neurons are far more complicated than such over-simplified models. In fact, the existence of deterministic chaos was confirmed experimentally with squid giant axons and other biological neurons. Moreover, it was also verified that nonlinear dynamics producing the nerve chaos can be understood in the framework of nerve ODE like the Hodgkin-Huxley equations and the FitzHugh-Nagumo equations. These results clearly showed that characteristics of real neurons are not so simple and static as linear threshold elements , but more complicated and actually chaotic.

Even if the deterministic chaos in the real neurons can be well described by the nerve ODE, these equations are too complicated to be adopted as constituent elements for large-scale artificial neural networks. It is a lesson we have learnt from deterministic chaos that complicated phenomena can be not rarely explained by simple deterministic dynamics. From this motivation, a simple neuron model with chaotic dynamics, which can reproduce the nerve chaos qualitatively, was proposed on the basis of physiological properties of relative refractoriness and a continuous stimulus-response curve at the axon hillock of the neuron. Further, the chaotic neuron model is generalized as a fundamental element of "chaotic neural networks" to investigate spatio-temporally chaotic neurodynamics and its possible functional roles in artificial neurocomputing[1]. The model of chaotic neural networks is a natural extension of conventional discrete-time neural network models like the McCulloch-Pitts model , the discrete-time Hopfield networks and multi-layer Perceptrons because the model of chaotic neural networks includes the conventional neural networks as special cases by adjusting values of its parameters. In other words, we can easily introduce chaotic dynamics into the conventional neural networks toward studies of computational abilities of deterministic chaos in artificial neural networks.

The model of chaotic neural networks can produce abundant spatio-temporal dynamics through nonlinear interactions among component chaos. For example, the spatio-temporal dynamics allows a neural network to move chaotically over constrained but rich fractal structure in the phase space without getting stuck at local minima. This ability has been applied to dynamical linking of patterns stored with synaptic weights of superposed covariance matrixes in associative memory networks and also to dynamical searching for approximate solutions of global optima in combinatorial optimization networks. The model of chaotic neural networks can be further extended to (1)"transient chaotic neural networks" with transient chaotic dynamics which realises a kind of deterministic simulated annealing called "chaotic simulated annealing" by controlling the bifurcation structure from strange attractors to an equilibrium point[2] and to (2)" asynchronous chaotic neural networks" with which analog time intervals between action potentials can be analysed in relation to possible coincidence detection of cortical neurons and utilized for temporal coding and processing[3,4].

Nonlinear spatio-temporal dynamics of networks composed of chaotic elements with high potential of computation is an attractive research subject not only as models of biological neural networks but also as models for chaotic parallel distributed processing which is classified as one of a new generation of artificial analog computing.

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