Preface

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More than 90 years ago, Henri Poincaré and some other scientists recognized complex phenomena that were often observed in deterministic dynamical systems. In the 1960s, the beginning of the computer age, Lorenz, and Ueda and Kawakami demonstrated strange attractors in convective flow systems and nonlinear resonance circuits, respectively. However, most of the scientists were not attracted to such complex phenomena, because the concept of chaos had not been accepted in scientific communities yet. Besides, it was still believed that the complex phenomenon could not have been derived from a simple deterministic rule, and if it could be, it must be a product of wrong computation in computers or unexpected contamination in experiments. In 1971, Ruelle and Takens found a new type of attractor in their mathematical studies of hydrodynamic turbulence. The attractor is different from point, periodic, and quasi-periodic attractors, each of which possesses a physical reality such as a steady state, oscillations with a single period, and oscillations with plural incommensurable periods. This attractor was named *strange attractor.* In 1975, Li and Yorke presented an impressive article "Period Three Implies Chaos," where they proved rigorously an existence of chaos in one-dimensional continuous maps. In 1976, May demonstrated how a simple model of population dynamics causes unpredictable complex oscillations. Then, physicists, mathematicians, and engineers gradually recognized that chaotic phenomena really exist in nature. After these articles, theoretical and experimental research on chaos remarkably progressed, and we have now a good knowledge of chaos in fluid, condensed matters, biological systems, chemical reactions, and even in galaxies. The fact that chaos is ubiquitous and results in rich dynamics of nature have changed our traditional views of nature.

Two present major problems with chaos are having a deep understanding of the complexity of chaos and clarifying roles of chaos in nature. These problems are just what was discussed in one special session of the *International Conference on Fuzzy Logic and Neural Networks* in 1992.

It is our great pleasure to provide the readers a nice introduction to chaos by one of the pioneers of chaos study, Otto Rössler. Since a concept of chaos is

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INTERNATIONAL JOURNAL OF INTELLIGENT SYSTEMS, VOL. 10, 1–3 (1995)

CCC 0884-8173/95/010001-03

deep, it may well be related to various branches of study. We hope that engineers who are approaching application studies of chaos will also learn various implications of chaos through Rössler's introduction.

The mathematical study of chaos has been limited to systems with a few independent variables. With an increasing interest in complex systems, systems with large degrees of freedom begin to be highlighted. What is the "chaotic" behavior in such a large system? Rössler proposed hyperchaos as a model of turbulence as well as a model of cognitive hierarchy, where the system's complexity increases step-by-step with an increase in the number of positive Lyapunov exponent. However, drastic change of the phase space structure (attractors) is clearly seen with an increase in the dimension, the number of independent variables, even from three to four. Rössler, Kundsen, Hudson, and Tsuda clearly demonstrate "super" strange attractors. This remarkable effect obtained by a slight increase in the dimension will lead us to the caution that the complexity of large systems could be much more complex than expected.

The conventional study of artificial neural nets has been limited to equilibrium phenomena, and/or near-equilibrium phenomena such as a relaxation process to an equilibrium state. However, the study of artificial nets has been widely done as a typical system with large degrees of freedom, and dynamic processes of the network activity are recently highlighted, where a cortical tissue is modeled by neural nets that include chaos. This special issue also treats this subject. Barna discusses effects of learning in the olfactory bulb in this context. Basti and Perrone propose a new axiomatic system where dynamical systems can be treated. They also made a dynamic perceptron, thereby succeeded in getting a high-level performance of detecting high-speed particles.

On the other hand, it is indispensable for a better understanding of the complexity to investigate how the complexity is expressed in the natural world and what roles the complexity has in various natural systems. From this point of view, one of the most interesting subjects is the brain. Actually, chaotic activities of neurons and biological neural networks have been clearly demonstrated, and brain functions are recently being argued in connection with the chaotic activity. A new challenge to solve the intelligence of the brain has started.

In this special issue, Freeman explains principles of the mechanism of information processing in the brain due to chaotic dynamics. Information is transmitted to the brain at the microscopic level by single neurons, but it is operated at the macroscopic level by neural populations within the cortex. Chaos plays its most important role when information is transferred and transformed by state changes between neurons and neural populations. He emphasizes that the brain consists of dynamical systems connected to each other, and processes of operations are done by dynamics. Neurons are not digital switches, and the brain is not a digital device.

Aradi, Barna, Erdi, and Groble, and Liljenstrom point out in this special issue that a memory state of most associative memory models corresponds to a stable stationary state and rich complex dynamics of biological neural networks are often neglected. Aradi et al. suppose that limit cycles and strange attractors might also be involved in computation with attractors and give a mathematical model of the olfactory bulb on which odor information is projected from sensory receptors in nose. The bifurcation sequence and dynamics of the model which depend on the lateral connection strength between mitral cells are investigated, and the character of the model as an associative memory that can process time-dependent inputs is illustrated. Liljenstrom gives a three-layer model of the olfactory cortex on which odor information is projected from the olfactory bulb in order to investigate roles of the dynamics for learning and associative memory processes. The model reproduces dynamical features of the olfactory cortex, and it is illustrated that effects of a neuromodulator can be used for improving associative memory performance by reducing recall time and increasing fidelity.

The information processing mechanism in the brain discussed at present in connection with chaotic dynamics is one of the most advanced scenarios of roles of chaos in nature, although many problems have not been solved. If the roles are well understood along with the complexity of chaos, the complexity will be utilized for information processing in artificial systems. We believe that serious studies on the fundamental theory of chaos, experimentally observed chaos in the brain and their technological applications prove in the near future that chaos is essential for novel intelligent systems.

This special issue was planned to publish results of a special session, "Chaotic Complexity," in the *International Conference on Fuzzy Logic and Neural Networks* that was held in Iizuka, Japan, during July 19–22, 1992.