Chapter 22
Challenges of Complex Systems in Cognitive and Complex Systems

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ABSTRACT

After an introduction the chapter analyzes complex systems and the evolution of the embodied mind, complex systems and the innovation of embodied robotics, and finally discusses challenges of handling a world with increasing complexity: Large-scale networks have the same universal properties in evolution and technology. Considering the evolution of the embodied mind, we start with an introduction of complex systems and nonlinear dynamics, apply this approach to neural self-organization, distinguish degrees of complexity of the brain, explain the emergence of cognitive states by complex systems dynamics, and discuss criteria for modeling the brain as complex nonlinear system. The innovation of embodied robotics is a challenge of complex systems and future technology. We start with the distinction of symbolic and embodied AI. Embodied robotics is inspired by the evolution of life. Modern systems biology integrates the molecular, organic, human, and ecological levels of life with computational models of complex systems. Embodied robots are explained as dynamical systems. Self-organization of complex systems needs self-control of technical systems. Cellular neural networks (CNN) are an example of self-organizing complex systems offering new avenues for neurobionics. In general, technical neural networks support different kinds of learning robots. Embodied robotics aims at the development of cognitive and conscious robots.

INTRODUCTION

Since more than two thousand years, philosophers, artists, and engineers had thought about artificial minds. Since hundred millions of years, the natural evolution on Earth has developed nervous systems with increasing complexity. They work according to algorithms of neurochemistry and equip organisms with self-adapting, self-controlling, and self-conscious features. But the laws of evolution

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could also admit completely different forms of life on different material basis – and perhaps they have emerged elsewhere in the universe. Therefore, humans and animals are only special cases of intelligent systems which have emerged on Earth under more or less random conditions. They are neither goals nor in the centre of evolution. Traditional AI had tried to imitate the human mind by symbolic programming with only modest success. In a technical evolution of embodied robotics, artificial forms of life and self-conscious systems could emerge with new self-organizing features. But, like in natural evolution, self-organization does not automatically lead to desired results. Therefore, controlled emergence is a challenge of future neurorobotics. A new moral responsibility is demanded in order to handle human-robotic interaction which is evolving in a technical co-evolution.

COMPLEX SYSTEMS AND THE EVOLUTION OF THE EMBODIED MIND

Complex Systems and Nonlinear Dynamics

The coordination of the complex cellular and organic interactions in an organism is built upon a kind of self-organizing control. That was made possible by the evolution of nervous systems that also enabled organisms to adapt to changing living conditions and to learn from experiences with their respective environments. The hierarchy of anatomical organizations varies over different scales of magnitude, from molecular dimensions to that of the entire central nervous system (CNS). The research perspectives on these hierarchical levels may concern questions, for example, of how signals are integrated in dendrites, how neurons interact in a network, how networks interact in a system like vision, how systems interact in the CNS, or how the CNS interacts with its environment. Each stratum may be characterized by a dynamical system determining its particular structure, which is caused by complex interactions of subsystems with respect to the particular level of hierarchy.

In general, a *complex dynamical system* is a time-depending multi-component system of elements with local states determining a global state of the whole system. In a planetary system, for example, the state of a planet at a certain time is determined by its position and momentum. The states can also refer to moving molecules in a gas, the excitation of neurons in a neural network, nutrition of organisms in an ecological system, supply and demand of economic markets, the behavior of social groups in human societies, routers in the complex network of the internet, or units of a complex electronic equipment in a car. The dynamics of a system, i.e. the change of system's states depending on time, is represented by linear or nonlinear differential equations. In the case of *nonlinearity*, several feedback activities take place between the elements of the system. These many-bodies problems correspond to nonlinear and non-integrable equations with instabilities and sometimes chaos (Mainzer, 2007).

From a philosophical point of view, mathematical *linearity* means a strong concept of causality with similar causes or inputs of a dynamical system leading to similar effects or outputs: small changes in the parameters or small perturbations added to the values of the variables produce small changes in subsequent values of the variables. Further on, composed effects of linear systems can be reduced to the sum of more simple effects. Therefore, scientists have used linear equations to simplify the way in which we think about the behavior of complex systems. The principle of superposition has its roots in the concept of linearity. But, in the case of nonlinearity, similar causes lead to exponentially separating and expanding effects: small changes in the parameters or small perturbations added to the values of the variables can produce enormous changes in subsequent values

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