G-CSC Kolloquium

Bottom-up and top-down approaches in Computational Neuroscience

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Abstract

Higher brain functions emerge from the cortical neuronal network, which is among the most complex structures found in nature. Its dynamics is exhibited on many spatio-temporal scales, and its functional role is presently not understood. Furthermore, in contrast to many other complex systems, the structure of the brain is not static but undergoes a continuous activity dependent reorganization. The research area of Computational Neuroscience attempts to organize the experimental observations into coherent mathematical models and to build brain-like machines. The bottom-up strategy attempts to construct biologically realistic neuronal network models based on the detailed knowledge of the constituting components. The assumption is that with sufficient accuracy in structure and dynamics, the correct functions will emerge. As an example, I will discuss a multi-layered model of a cubic millimeter of brain tissue responsible for higher brain functions. The model contains roughly 100,000 nerve cells and 1,000,000,000 contacts between the cells, known as synapses. The dynamics of such complex systems is rarely accessible to analytical treatments. Therefore, progress in Computational Neuroscience relies on the availability of efficient simulation techniques and super-computing facilities, which I will briefly review. However, the bottom-up approach alone may ultimately be insufficient to achieve an understanding of brain function. For this reason, we also incorporate top-down approaches in our research, such as investigating possible neural substrates for behavior adaptation algorithms developed in Machine Learning. The challenge is to discover how system-level learning is implemented by synaptic plasticity. To illustrate this approach, I will present a neuronal implementation of actor-critic temporal-difference learning. The model shows how learning results from the interaction of the neuromodulator dopamine with the dynamics of the network. Such research provides a link between network theory and dopamine related diseases like Parkinson's.