Neuromorphic artificial intelligence, Robot control, Medical / Healthcare

Development of artificial neural networks with brain-like structure and function and evaluation of their learning performance

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Abstract

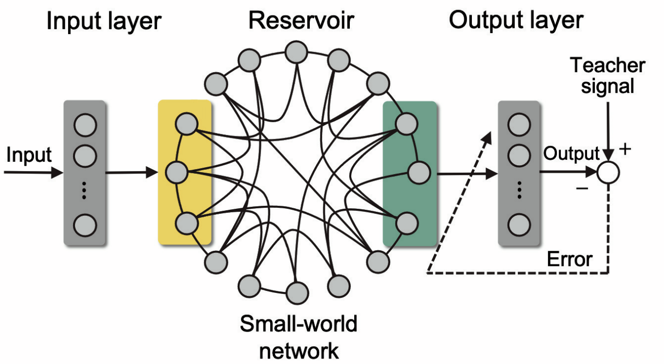
The brain is an enormous network of a huge number of neurons, which is neither fully regular nor fully irregular but it is very complex. Neural activity on this network is thought to process information and enable animals to behave intelligently. We introduce the structural properties of brain networks into artificial neural networks and analyze their neural dynamics to improve their learning performance and deepen our understanding of the relationship between brain structure and function. Using a small-world property, a representative structural property of brain networks, we successfully developed recurrent neural networks with efficiency of information propagation and robustness against structural changes.

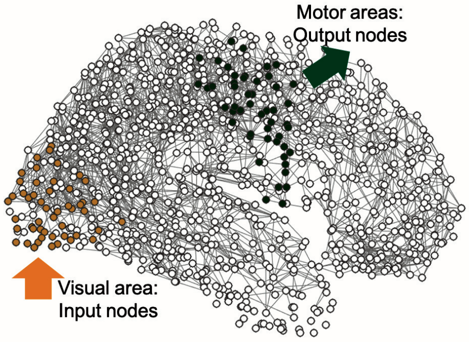
Background & Results

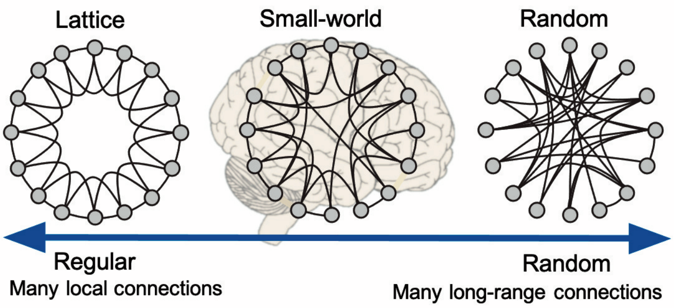
The small-worldness of brain networks is the property that there are many local connections, i.e., clusters, between brain regions and a few long-range connections, i.e., shortcuts, which can propagate information efficiently and quickly. We used echo state networks (reservoir computing), a type of recurrent neural networks, to investigate how the property influences neural computation. A typical echo state network has a randomly connected network (reservoir) with fixed weights and learns output time-series from input-induced complex dynamics in the reservoir network. We implemented the small-world property into the reservoir networks and evaluated their performance in time-series learning tasks. It is found that local connections enables the networks to robustly learn them in a wide range of a network parameter, and long-range connections makes information propagation fast. In contrast, random reservoir networks with many long-range connections are sensitive to the network parameter and performs well only in a very limited range of the parameter, and input information fades out between input-output pathways in reservoir networks consisting of only local connections. In addition, we developed echo state networks based on anatomical connectivity actually measured from human brains and conformed that the human brain reservoirs have the same learning property as the above artificial reservoirs. Furthermore, we constructed small-world networks using a spiking neuron model which behaves more like biological neurons. Simulation of the model showed that many local connections reduced the complexity of neural activity, and thus, exhibited a similar tendency to empirical observations in human electroencephalography studies, suggesting that they might be robust to structural changes as the above.

Significance of the research and Future perspective

Our studies on brain-inspired artificial neural networks aim to not only improve their learning performance but also understand the information processing in the brain and evolutionary and developmental origins of brain networks. Animals can adapt to changing environments robustly and quickly, acquire functions through experience, and achieve their goals autonomously with their very low-power-consumption brains. Elucidation of neural mechanisms of such intelligence leads to development of neuromorphic artificial intelligent and robotic systems that can realize such information processing and behavior. We are also trying to understand mechanisms of disorders such as autism spectrum disorder by simulating atypical brain networks.







Patent

Treatise
Kawai, Yuji; Park, Jihoon; Asada, Minoru. A small-world topology enhances the echo state property and signal propagation in reservoir computing. Neural Networks. 2019; 112: 15-23. doi: 10.1016/j.neunet.2019.01.002
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Keyword neural network, complex network, small-world network, reservoir computing, brain-inspired computing