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Simulation of Brain Nervous System Based on Complex Networks

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ABSTRACT

The aim of the paper is to simulate the brain nervous system based on complex networks. Complex networks provides a new view for brain network, and the brain nervous system can be abstracted to a network. In this paper we delineate the simulation process to brain nervous system by complex network and computer algorithm. By the logical definition, we can abstract the node and edge to set up the brain nervous system networks with the different algorithms. The simulation results imply that it is feasible to simulate brain nervous system network based on complex networks with brain anatomical and functional architectures.

Introduction

Brain is an import body that has many kinds of cognitive behavior, such as feeling, thinking, language, character and so on, meanwhile it has the functions of learning, memory, association and so on by Tang et al. (2006). In the anatomy view, the brain is one of the most complex organization and architecture that is composed of neurons, that is nerve cells by the introduction of brain (2011). In the quantity, there are about millions and millions neurons in the brain, and every neuron has ten thousand chances to connect the other neurons.

Neuron is a kind of highly specialized cells by Rinart et al. (1999), and has the same architecture and character as other cells, in the neuron the cells connect each other by synaptic. In the function, neurons is the basic unit for nervous system to organize and transmit information, and has the powerful electrochemical signal acquisition and transmission capacities, they achieve the information communication and transmission by accepting, integrating, and transmitting. Of course, the neuron has its own characters, such as Hebb rules.

From anatomy view, brain nervous system is a complex body including central nervous system and peripheral nervous system by Fuchs et al. (2007), He et al. (2007), Zhao et al. (2007), Eich et al. (2009), Schinazi and Epstein (2010), from the organizations of the system, it includes brain cortices and neurons. In this paper, we discard the nervous body itself in clinical view, and want to discuss the research methods from complex networks and computer algorithm.

Methods

Complex network

Complex network studies are a new perspective for all the other research fields, such as medicine, engineering, people relations and so on by Dorogovstsev and Mendes (2002), Newman (2003), Boccaletti et al. (2006), Costa et al. (2007), Bullmore and Sporns (2009). It had been extensively studied on the theory and application in these fields and had gotten so many useful results. Complex network is to explore the real world system based on graph theory and computer network. Recently, the complex networks studies on brain functional network have come out many excellent characters whether on the anatomical networks or the functional networks with the simulation and experimental data.

Based on graph theory, every real system can abstract to a network by the node and edge definitions with the real meaning. For the node, it stands for the basic unit of the system, and for the edge, it stands for the information relation or other connection relation. The network can be gotten by the iteration or growing algorithms based on node and edge so as to simulate the real system, then we can compute the network topology characters to seek the characteristic of the real system.

Complex network topology characters represent the node and network characteristic on the effectiveness, relation, intrinsic quality, and so on. Among them, the node and node degree, average path length and clustering coefficient are the basic elements, the other characters can be gotten by the computing of the basic elements. The node character represents the individual characteristic of the network, the node degree represents the node relation in the network, they can delineate the local and global characters of the network. The average path length represents the efficiency of the network by the path length. The clustering coefficient represents the group ability of the network, meanwhile it represents the efficiency of the network by the modular.

Logic definition

In the brain nervous system, there are so many neurons that take part in the cognitive actions, so it is impossible to delineate the thorough and real architecture of the brain nervous system. In the researches on brain nervous system, we use logic definition to simulate the system by Flavell (1971), Zhu (2010), Martielli et al. (2013). With simulation, we can discard the experimental environment partly to explore the characteristic of the huge system. With the logic definition, we can focus on the functions of the nervous system based on the structure.

By logic definition, we can put emphasis on the characteristic abstraction of the network including the node and edge. For the brain nervous system, from the internal structure, it is composed by the neuron in the micro-level, and from the external structure, it is composed by the nervous organization in brain cortices from the macro-level, so we can abstract the real meaning of the neuron and cortices to set up the network.

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Computer algorithm

Algorithm is a series instructions of the information process, by the algorithm we can describe a detailed process or a complex process by Aho et al. (1983). Generally, the algorithm is composed by the initial state, growing process and end state in network, of course, including special and effective process design for growing. Algorithm is a kind of strict logic reasoning or scientific description, it stands for the efficient of the network in time complexity and space complexity.

With computer algorithm, the brain nervous system can be simulated to a complex network, and with the special algorithms, such as query algorithm, updating algorithm, changing algorithm, we can get the characters of the networks, that is the brain nervous system characters.

Simulation

Simulation is a kind of methods to model the real system. Sometimes, it is difficulty to make research on the complex system or the fine system, especially the special research object, such as people brain, we can not put it in the experimental environment always to find out the characters, relation or other profound explorations.

Simulation is to set up a prototype of the real system, then to make research on prototype by all kinds of methods, such as mathematical, statistical and dynamical computations, by the prototype, we can return to study the real system. By simulation, we can model the real system to a theory model, and make study on the model so as to explore the real system, then modify the model by the real system with the parameters, thus it can form a recurrent process between the real system and model, and at last we can get our simulation results and characteristic of the real system.

Results and discussion

Based on above methods, we can simulate the brain nervous system to a complex network, and then compute its dynamics topology characters to find the characteristic of brain nervous system.

Firstly, by logic definition, we abstract the node of the network, for the internal structure, we define the neuron as the node, if a node takes part in the cognitive actions, it can be looked on as a node of the network, in this sense, we don't take the space structure of the neuron into account. From the anatomy, the neuron is connecting each other from space, but it is not all the neuron taking part in the actions, so we abstract the node from the functional view. The edge is the precedence relationship to take part in the action, perhaps the adjacent or neighbor, the connection can be directional or un-directional, and also can be sequential. For the external structure, we abstract a brain cortices region as a node, we all know it is not a single brain region that takes part in the cognitive action, there are some or many cortices in some cognitive action by Schlosser et al. (2006), Schott et al. (2013); the edge is the space structure of the brain cortices.

Secondly, we can design the construction algorithm to set up the brain nervous network. Based on the logic definition of node and edge, we can simulate the formation process of brain nervous system in corresponding to the concrete tasks. By the modeling algorithm, we can get a brain nervous complex network. Because of the different abstractions of node and edge, the complex networks can be multi-characteristic, for example, by the node and brain cortices, we can get different levels network, that is hierarchical network; also we can get different modular network, that is bi-modular, tri-modular or multi-modular network, that is modular network.

Thirdly, we simulate the nervous system and compute the network topology characters to find the characteristic of the network, and to verify the real system on the model. About the degree and degree distribution, we can get the brain nervous system action characters with the neuron and nervous system; about the average path length, we can get the action efficiency; about the clustering coefficient we can get the action modular.

At last, we make the simulation with the experimental data and discuss the dynamics topology of the nervous network. Based on brain anatomical and functional basis, by computation of average path length and clustering coefficient, we got that the brain nervous system had the characteristic of small world, that is a small world network by Fell and Wagner (2000), Sporns and Zwj (2004), Sporns and Honey (2006), Zhang et al. (2013). The nervous network had the shorter average path length and high clustering coefficient that implied the system effective. Based on the results, we can make deep research on the nervous system with the evolving mechanism, intelligence, cognitive characters and so on. Importantly, we can use the results to clinical researches. In the clinical patient, we can use the same method to set up nervous network of patient, so as to compare the results with normal person. We think that it will provide useful reference for the theory and practice research on medicine field.

Conclusion

In this paper, we propose a new prospective to simulate brain nervous system based on complex networks. Due to the large number of the neuron in the cognitive actions, we put forward to define logic unit to solve the difficulty from the function abstraction, meanwhile, the brain experiment is special and expensive, so we cannot repeat and waste the experimental environment to test our researches, so we advise to simulate the nervous system by a prototype. Of course, any reliable and right results need combine the real data, in our studies is the architecture of anatomical and functional, so the compellent and persuasive results need to be made deep and extensive exploration, so that it can be applied in the clinical practices.

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