# An Exploration of Artificial Brain White Matter Model of Dynamic Complex Networks

Fang Hui *

*Computer School*
Wuhan University
Wuhan, Hubei,, China

***Abstract* — Research of complex network is widely conducted and applied in numerous fields. Its core issue is the relationship between nodes and edges, but its main direction is structural evolution, power distribution and propagation characteristics. In a dynamic complex environment, the change of the edge weight has the potential to be improved, the traditional consideration is the local characteristics, while it is difficult to achieve the goal of the overall optimization objectives. The white matter of the brain's biological characteristics and complex network has many similarities, especially on axons myelin and edges weight. In this paper, we try to explore establishing an artificial white matter model of brain, and focus on the impact of the environment on complex networks.**

***Keywords - dynamic complex network; white matter; myelin; schwann cell***

## I. INTRODUCTION

Complex network is a branch of graph theory. There are all kinds of network existing in our real world. From the real world complex system, we could abstract a network module which consists of correlative individuals and the relationship among the individuals. The network models we abstracted is referred as complex network. There are three properties of complex network, including: 1) small world[1]; 2) scale free[3,4]; 3) community structure[5]. There are some matters when dealing with models which are built based on complex networks, such as:

1) The model excessively depends on fixed models. With this excessively dependence, the model built upon complex networks is lack of intelligence, adaptivity, and a dynamic adaptive mechanism along with the changes of environment. Therefore, this kind of model cannot be able to deal with the dynamic networks conditions.

2) Analysis objects of the above models are unified, isolated and immobilized. It lacks of regional data capture, integral analysis and evaluation, and the capability of integral regulation to reach the optimized adaptivity.

Complex network is commonly applied in various realms. However, its describing ability is inadequate under some complex dynamic environment. Thus, it is necessary to come up with a control model with the following two characteristics:

1) The model is capable of perceiving diverse dynamic network environments, capturing and evaluating environmental data. Besides, if current network does not satisfy the environmental requirements, this model is able to provide adaptive value which regulates networks;

2) As for net edges of the whole region, the model could integrally consider the attributes of relative multiple edges, and systematically provides the adaptive value for the whole region;

This article aims at the deficiency of complex networks which lacks of dynamical changes for edge-weight relationship upon the environmental effects.

## II. INSPIRATION FROM BIO MODEL OF WHITE MATTER SYSTEM

Human brain is made of two mainly parts, including white matter and grey matter. Grey matter is a place where brain processes calculation and keeps memory. It is located at the surface of the brain and consists of closely packed neurons. Grey matter is a main part in human brain process thinking. It is an arithmetic unit, and a memory unit as well.

Under grey matter, there is a white base named White Matter. More than half of human brain is made of white matter. Whereas, the proportion of white matter in other animals is weight less than it in human brain. Therefore, white matter could be considered to be one of essential developed features which distinguish human brains from other animals' brains.

For a long time, scientists are agreed the following statement, it is the structure and process speed of grey matter that decide the flexibility of thinking, loading speed of memory, and capacity of memory. However, recent researches indicates that white matter plays a crucial part in humans' thinking activities.

In central and peripheral nervous system, the periphery of nerve fiber is wrapped with myelin sheath which is made of myelin. Around axon, myelin sheath is usually spirally arranged, and mostly follows membranous structure. Each myelin sheath of axon is not continuous, but discrete. It is interrupted by Ranvier's nodes every certain distance. Nerve axon is exposed at Ranvier's nodes.

In this system, a sausage-shape glial cell, called Schwann cell (SC), secretes myelin for peripheral nervous system's axon. Since it is hard to penetrate the epitheca which is made

DOI 10.5013/IJSSST.a.17.11.06

ISSN: 1473-804x online, 1473-8031 print

of myelin, neural signal is transmitted by jumping between Ranvier's nodes[6]. According to the research of white matter in human brains, it indicates two significant attributes of white matter:

1) White matter has the characteristic of dynamic evolution.

2) The improvement of brain functions presented in the integral evolution of some area in white matter.

If we take every neuron as a node, axon as the connection between nodes, white matter which is made of those connections has the two attributes, which is exactly the problems we need to solve for the dynamic complex networks. Therefore, studying the structure and mechanism of white matter provides a good angle to deal with the problems of dynamic complex networks by borrowing the organism mechanism of white matter.

## III. Bio Model of White Matter System

### A. Myelin

Myelin is a layer of lipid tissue, wrapping around axon of some neurons. Myelin could accelerate conduction velocity of nerve impulse with function of insulation. Structure of Myelin is shown in Fig.(1).

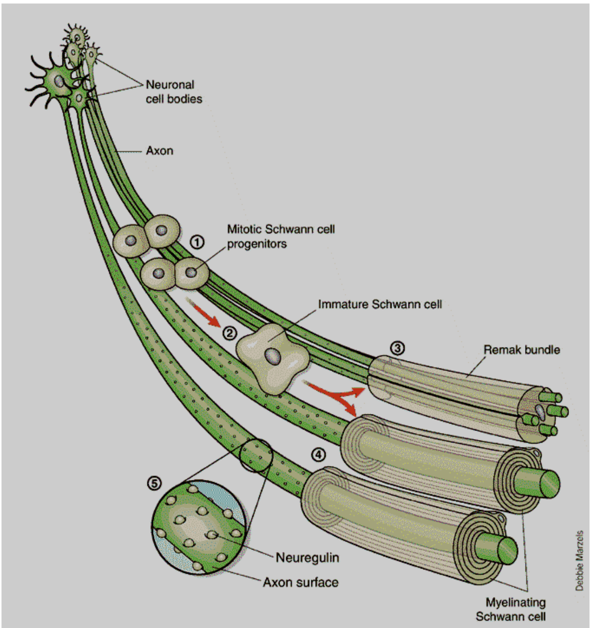


Fig. (1). Schwann cell differentiation [7]

### B. Schwann Cell(SC)

Schwann cell is the major cell that construct peripheral nervous cell. It participates in several essential bio functions of peripheral nerves, including transmitting nerve implies, being part of nerve's generating and regenerating, nourishing neuron, generating nerve extracellular matrix, regulating activities of motor neuron and mediating antigens. SC is divided into two groups, myelinating and non-myelinating. Nerve axon wrapped with myelinating SC form myelin sheath.

### C. Ranvier's Nodes and Myelination of Axon

In the nerve system, axons of nerve cells is wrapped by myelin. However, myelin cannot completely wrap axons. It segments the wrapping, where the naking parts are called Ranvier's Node (RN).

Having received myelination signals, precursors of SC become mature SC. As more SC wrapping on the axons to finish the process of myelinating axons, the degree of myelinating of axons is a significant index of evaluating the neural system. According to the research of white matter, as thickness of myelin increasing, input signals of neuron is strengthen.

### D. Glial Cells (GC)

Except cells other than neurons, Glial Cells (GC) is widely distributed in central neural system. It is with function of supporting, nourishing neurons, as well as absorbing and adjusting some active substance. Regenerating of neural axons requires GCs' navigation

### E. Semaphorin (SMP)

Semaphorin (SMP) is membrane glycoproteins secreted by white matter. It unites with corresponding receptor to stimulate kinase, to adjust RhoGTPase, and to regulate cells' activities by adjusting R-Ras control integrin and cytoskeleton[8-10]. Semaphorin plays an important role in several process including axon guidance, immune regulation, and tumor growth and metastasis. In white matter neural system, semaphorin navigate SC movingly cover axons.

### F. Neuregulin (NRG)

Neuregulin is an epidermal growth factor (EGF). There are four kinds of NRG, including NRG1-4. This NRG is mainly responsible for cells' generating and divergent[11]. Through acting on receptor of EGFs, or namely ErbB, it plays an essential part in neural system growth and damage recovery. Taking ERG1 as an example, in peripheral neural system, neurogenic NRG (NNRG1)'s signal is extremely crucial in SC's selection for axons. Since ErbB receptors accept NNRG1, SC is able to distinguish the characteristic of axons and then to form myelin. Neurons of the high performance exogenous NRG (ENRG1) make SC not be recognized and chosen, thus SC cannot wrap around axons to become myelin[12]. Therefore, NRG is an essential signal for SCs' myelinations. Consequently, corresponding conclusion can be reached.

### G. Myelination Signal

Concentration signal of neurogenic NRG1 is an indicator of myelination. As signals of NNRG1 is strengthen and exceeds some threshold value, it eventually leads to myelination of axons.

### H. Demyelination Signal

As concentration signal of exogenous NRG (ENRG1) exceeds some threshold value, it indicates that SC become immature, then the thickness of myelin decreases.

### I. *Neurotrophin*

Neurotrophin has effect on axons' growth, migration of SCs, and cells' disease[13]. Under the effect of neurotrophin, mature SC is able to wrap daround myelin. If neurotrophin does not reach the threshed value, SCs cannot transfer on myelin.

### J. *Synapse*

In neurology, synapse is an end point of axons. It is the connection of two neurons. Synapse transfers chemical signals from one neuron to another.

The biological characteristic of synapse indicates the targeted nature of transferring neural signals. In the system of white matter, it in fact exists multiple neurons connecting to each other. In order to simplify the model, it is assumed that only a signal one-way axon connects two neurons, where synapse indicates the direction. Therefore, there are at most two directed connection between two neurons.

## IV. PROCESS OF SCS' TRANSFERRING STATUS

In the system of white matter, SC holds a crucial role. Its status will eventually leading to a process of myelination axons or demyelination ones. There are two ways to alter status of SCs: as a positive stimulus is received, like the concentration of NRG increases, SCs continue wrapping axons, which is the process of myelination; whereas negative stimulus is received, like decreasing the concentration of NRG, there is no any change to myelination even become thinner, which is the process of demyelination.

In this model, there are three status of Mitotic SCs: progenitor, immature, and mature. Through the differentiation, SCs transfer from progenitor to immature and then to mature. The transferring process is activated after receiving some certain input signals, and status is changed according to the corresponding value of input signals. The result of divergent directly leading to two completely different consequents of SCs. The immature ones indicates demyelination, and reduce the speed of neural conduction; whereas the mature ones could speed up the process of myelination, which increase the speed of neural conduction. This is a crucial mechanism. The process of myelination is the fundamental of the model.

Fig. (2) illustrates the critical biological characteristic of SC in white matter model. Based on the above illustration, this article build a white matter model with some certain assumptions and some critical characteristic indexes being provided. Those characteristic indexes are used to build an abstract model which could distinguish the differences, self-adjusted, and dealing with signals.

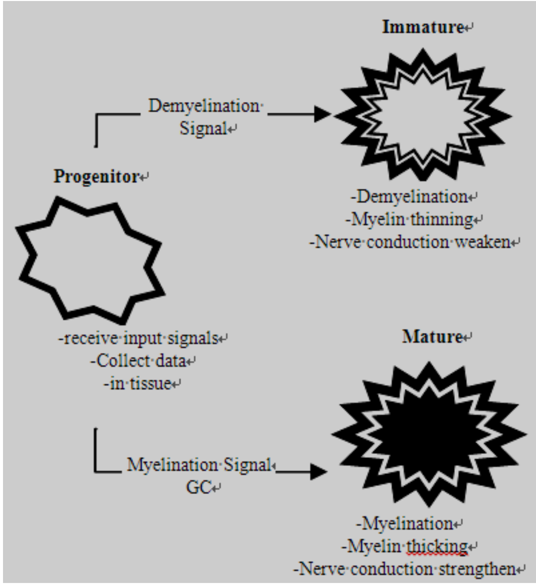


Figure 2.. The Transition of Swan Cell's status and signals

## V. SIGNALS IN WHITE MATTER MODEL

As mentioned above, it is the signals which representing the different status of tissues that operate the system. All kinds of signals tells SCs to transfer to two different status accordingly. One is responsible for the evolution of white matter system; and the other one takes charge of degeneration of neural conduction. According to some relative biological research, there are both interior and exterior influence on SCs. Table 1 provides the name and function of biological signals, which are used to build models.

TABLE I SIGNALS IN VARIOUS GUISES AND THEIR ABSTRACT MEANING

| Biological Signal | Function |
|---|---|
| Glial Cells | indicator of Myelination |
| Neurogenic NRG1 | indicator of Mature SC |
| Exogenous NRG1 | indicator of Immature SC |
| Neurotrophin | set of signals indicating general tissue strengthen |

Glial Cells wraps around neuron axons to form myelin; and consequently insulates the axons between Ranvier's nodes and secures the neural impulse efficient jumping conduction. The formation of myelin is a dynamic complex process. The delicate adjusting between neuron and glial cells is crucial in each stage of forming myelin. In peripheral neural system, SCs are the formation cells of myelin. There are three stages in forming myelin: having received axons' signals, SCs immediately proliferate and move towards axons; then, SCs extend along axons and wrapping up axons to form the prophase of myelination; finally, wrapping around axons, SCs become a dense myelin. Axon signals plays a critical role in activating and maintaining myelination. In traditional point of view, the axonal signals mentioned above is referred to Semaphorin and neurogenic NRG (NNRG1).

From the understanding of the bottom of natural ecosystem, this article selects and abstract all kinds of possible signals for using in the white matter model.

In the abstractive model, input signals which drives SCs to be mature is called myelination signals (MS), which eventually increase the density of NNRG1. As for the input signals which degenerate myelin, those are called demyelination signals, which eventually increase the density of ENRG1. The interactions between signals are shown in fig (3).

## VI. THE IMPLICATION OF WHITE MATTER MODEL RESEARCH AND ITS IMPROVEMENT OF COMPLEX NETWORK

In the research of complex networks, the description of edges is weight value which represents the attributes of edges. For example, in transportation network, weight value could be the flow of vehicles, vehicles' speed and so on. However, in describing presenting condition of the network, limiting on control variable of edge weight, in other words, is indirectly limiting edge weight.

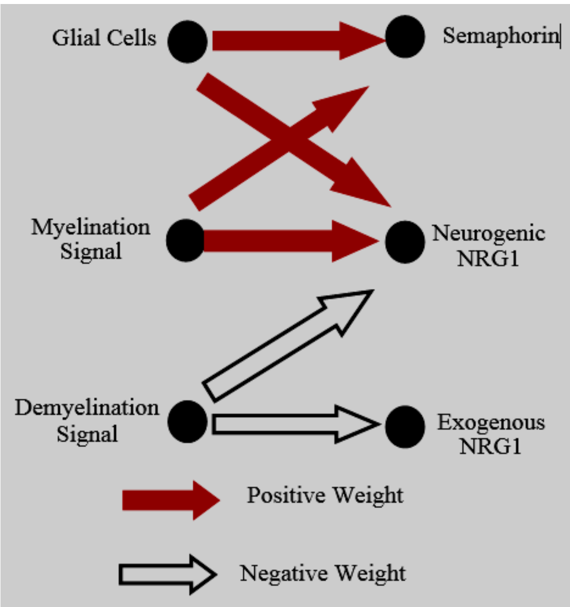


Figure 3. A representation of calculations performed by SCs, to derive the cells outputs through fusing together the signal inputs.

For example, the width of roads also determine that the flow of vehicle could only changes in a certain range; the width of roads regulates the speed as well. In order to more precisely present the attributes of complex network, using white matter model as a reference, a constraint is added on the edge artificial myelin.

Artificial myelin changes in a certain range. Through the regulation, the model could control the change of edge, therefore wedge value of edge is more adaptive to the environment. Fig. (4) shows the Structure of White matter model.

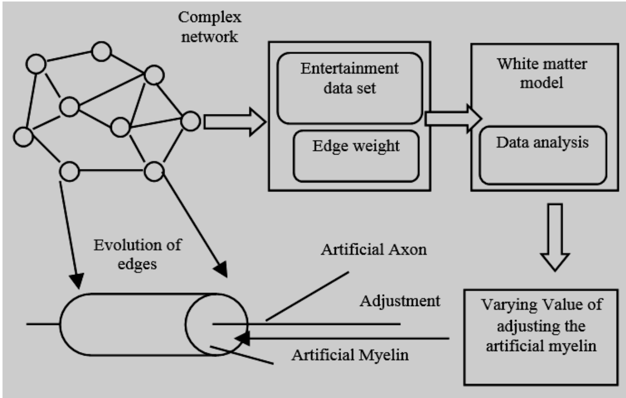


Figure 4. Displays the idea of white matter model.

In this model, we need to conduct research and study on the following several issues:

1) Edge weight's effect on constraint edge weight and constraints are in a mutual influence relationship. Since the diversity and dynamics of complex network, value of edge weight constantly changes along with changes of environment to adapt to the peripheral environment. White matter information model is capable of sensing the peripheral environment. As edge weight is not suitable for the environment, the model will provide an adaptive value for the constraint based on the model's evaluation for the environment. The adaptive value make the edge weight value change towards the objective requirement, and eventually adapt to the change of peripheral environment.

2) The reciprocal relationship between edges in White Matter Information Model. In the white matter information model, there are several mutual influenced relationship. All elements in the model, such as different edge weight value and artificial myelin, are interactive to each other. All parameters in the model cannot be controlled individually and independently. For example, in the transportation network, when a road is over crowd, widening the road might not be the answer. However, taking the neighbor roads into accounts and integrally adjusting those multiple roads could solve the problem better. Therefore, with fully considering the relationship among multiple edges and systematically adjust the constraint value of those multiple edges, the purpose of this model is to optimize the whole network by accessing an integral evaluation of multiple edges.

3) Complex environment's data evaluation by cell population. From the information model mentioned above, the main issue is based on the relationships among the elements, how to determine and test the efficiency and accuracy of the model. The model make use of a population made of multiple individual cells to monitor the whole network. Each individual submit an estimation of the

DOI 10.5013/IJSSST.a.17.11.06

ISSN: 1473-804x online, 1473-8031 print

environment based on the data each individual received. Then, the whole population composited of those individuals would provide results based on combined estimations. This kind of model is capable of integrally exam the network environment from each angels; also, it could avoid biases from specifications of the individuals' selections. White matter model is abstracted from biological behavior. Since the models are more close to biological process, the information model is built based on biological model.

In bio neural system, white matter is consists of hundreds of thousands of myelin and its peripheral neural system. White matter's information model take a dynamic control of the wedge value of the whole network. This model has external environment's signals as inputs of the system. Based on the sampling analysis of the difference signals' grouping, an artificial SC could submit its conclusion, myelination or demyelination.

White matter information model includes three main functions：

### *A. The Collection of Environmental Data, Provide the Basis for Artificial SC Conversion.*

In order to gather input signal, provided the individual signal acquisition, these individuals collect different combinations of signal sources according to environmental conditions, and then the collected signals will be assessed by algorithms. If the signals can get conversion influential results to artificial SC, submitted to the signal collections system, the resulting signal collection system collected according to many different individual collector finally send input signal to the artificial SC individuals.

### *B. Artificial SC to Complete the Conversion Based on the Data Logger*

Maturity of artificial SC directly affects the process of edges dynamic diversification in the white matter model, the first set of three states for artificial SCs under the white matter model, and after receive a entering information of the environment change, each will alter from a precursor state either to mature or immature conversion.

### *C. Evaluation of the Plurality of Artificial SC Population Statistics to Achieve Changes in the Myelin Sheath.*

Diverse types of artificial SCs is established. To the artificial SC population, the effects of different types of artificial SC entire extent of myelination of axons is different. Adoption of the final value of the weighted evaluation of these artificial SC populations of individuals to determine the resultant change is the myelination of axons or demyelination, which is the values of edge weight to increased or decreased.

## VII. CONCLUSION

Based on the description of the white matter model, the paper illustrate the operation mechanism of white matter. In the nervous system of the brain, white matter is a aggregation of connections between neurons, they are affected by the environment, constantly undergoing change, the white matter plays a vital role in the brain signal transmission, and, to a certain extent, brain white matter determines the quality of brain thinking activity.

This article first introduces the two major characteristics of biological white matter, which is just two features that can solve the problem of dynamic complex network as a usable reference, and then introduce specific biological system of white matter in brain.

Next, the article studies the biological characteristics of the white matter of the brain, including the basic structure and the function of each tissue, cell and material, furthermore the information of the signals transferring between them. It is these signals and biological stimuli that eventually lead to the constant evolution of the white matter, which is the result of the adaptive changes of the human brain in nature.

Finally, based on the biological model of white matter, this paper proposes artificial information model of white matter, comparing the structure and functions of the white matter system and the complex network, for the establishment of the white matter information model as the forward goal.

## ACKNOWLEDGMENT

This work is supported by the National Nature Science Foundation of China (No.61170306), the National Natural Science Foundation of China Youth Found (No. 41404076).

## REFERENCES

[1] Watts DJ,, "Strogatz SH. Collective dynamics of 'small-world' networks", nature, vol. 393, No. 6684, pp. 440-442, 1998.

[2] Wu J, Watts DJ, "Small Worlds: The Dynamics of Networks between Order and Randomness",Sigmod Record, vol. 31, No. 02, pp. 74-75, 1999.

[3] Barabási AL, Albert R, "Emergence of scaling in random networks", science, vol. 286, No. 5439, pp. 509-512, 1999.

[4] Barabási AL, Albert R, Jeong H, "Mean-field theory for scale-free random networks: Physica A", Statistical Mechanics and its Applications, vol. 272, No. 06, pp. 173-187, 1999.

[5] Strogatz SH, "Exploring complex networks",Nature, vol. 410, No. 02, pp. 24-27, 2001.

[6] R Douglas, "Myelination: An Overlooked Mechanism of Synaptic Plasticity",Fields in Neuroscientist, vol. 11, No. 05, pp. 528-531, 2005.

[7] Nave KA, Schwab M H, "Glial cells under remote control",Nature neuroscience, vol. 8, No. 11, pp. 1420-1422, 2005.

[8] Bagci T, Wu JK, Pfannl R, Ilag LL, & Jay DG, "Autocrine Semaphorin 3A signaling promotes glioblastoma dispersal", Oncogene, vol. 28, No. 40, pp. 3537-3550, 2009.

[9] Chen G, Sima J, Jin M, "Semaphorin-3A guides radial migration of cortical neurons during development",Nature Neuroscience, vol. 11, No. 01, pp. 36-44, 2008.

[10] Sadanandam A, Rosenbaugh EG, Singh S, Varney M, & Singh RK, " Semaphorin 5A promotes angiogenesis by increasing endothelial cell proliferation, migration, and decreasing apoptosis",Microvascular Research, vol. 79, No. 01, pp. 1-9, 2010.

[11] Friedrich RP, Schlierf B Tamm ER, Bosl MR, & Wegner M, "The class Ⅲ POU domain protein Brn-1 can fully replace the related Oct-6 during schwann cell development and myelination", Molecular & Cellular Biology, vol. 25, No. 05, pp. 1821-1829, 2005.

[12] Michailov GV, Sereda MW, Brinkmann BG, Fischer TM, Haug B, Birchmeier C, Role L, Lai C, Schwab MH, Nave KA, "Axonal

neuregulin-1 regulates myelin sheath thickness", Science, vol. 304, No. 5671, pp. 700-703, 2004.

[13] Zhou XF, Li HY, "Roles of glial p75NTR in axonal regeneration", Journal of Neuroscience Research, vol. 85, No. 08, pp. 1601-1605, 2007.