DOCTORAL THESIS IN COMPUTER SCIENCE
STOCKHOLM, SWEDEN, 2017

Computational Models to the Degeneration of Brain Networks and Other Complex Networks

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Joint doctoral dissertation which, with due permission of the KTH Royal Institute of Technology and of the Albert Ludwigs University of Freiburg (ALUF), is submitted for public defence to take place on Friday September 29th at 13:30h, F3, Lindstedsvägen 26, KTH, Stockholm, Sweden.

Abstract

The title of this thesis is Computational Approaches to the Degeneration of Brain Networks and Other Complex Networks.

Networks are ubiquitous with several levels of complexity, configuration, hierarchy and function. Many micro- and macro-scale biological or non-biological interactions define complex systems. Our most sophisticated organ, the brain, accommodates the interaction of its billions of neurons through trillions of synapses and is a good example of a complex system.

Network structure has been shown to be the key to determine network functions. For instance, communities or modules in the network explain functional segregation and modular interactions reveal functional integration. Moreover, the dynamics of cortical networks have been experimentally shown to be linked to the behavioral states of the animal. The level of rate and synchrony have been demonstrated to be related to sleep (inactive) and awake (active) states of animals.

The structure of brain networks is not static. New synapses are formed and some existing synapses or neurons die due to neurodegenerative disease, environmental influences, development and learning, etc. Although there are many studies on the function of brain networks, the changes by neuronal and synaptic degeneration have not been so far in focus. In fact, there is no known mathematical model on the progressive pattern of synaptic pruning and neurodegeneration. %Despite the therapeutic and diagnostic potential to neurodegenerative diseases, for example, models of synaptic pruning and neurodegeneration are very rare.

The goal of this dissertation is to develop various models of progressive network degeneration and analyze their impact on structural and functional features of the networks. In order to expand the often chosen approach of the "random networks", the "small world" and "scale-free" network topologies are considered which have recently been proposed as alternatives. The effect of four progressive synaptic pruning strategies on the size of critical sites of brain networks and other complex networks is analyzed. Different measures are used to estimate the levels of population rate, regularity, synchrony and pair-wise correlation of neuronal networks. Our analysis reveals that the network degree, instead of network topology, highly affects the mean population activity.

Network analysis is meaningful only when the connectivity is extracted experimentally with good level of accuracy. On the basis of the observed co-dependence of neural network dynamics and structure, our connectivity assessment from the analysis of population activity should be significantly improved in future studies. Other future direction aims to formulate degenerating patterns based on experimental data and design effective compensation mechanism to network damage.

ISBN 978-91-7729-514-3 | TRITA-CSC-A-2017:19| ISSN-1653-5723 | ISRN-KTH/CSC/A--2017/19-SE