# NEURAL AND SOCIAL NETWORKS: STRUCTURE AND DYNAMICS

*Précis of the Dissertation*

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Budapest, 2004

# About this dissertation

This Work consists of two parts. In the first one I study possible temporal pattern generating mechanisms of the septo-hippocampal system using methods of computational neuroscience. The second part deals with graph theoretical description of social networks.

# Temporal pattern generation in the septo-hippocampal system

## Introduction

The hippocampus is an evolutionary old brain structure located in the medial part of the temporal lobe. This area was first named and described by the Italian anatomist and surgeon Giulio Cesare Aranzi in the 1500s. The shape of the hippocampus reminded him to a seahorse, hence the name. Experimental results have shown that the hippocampus and strongly associated structures (e.g. septum, entorhinal cortex) serve to generate long-term memory traces. Clinical evidence indicates that damage of the hippocampus results in retrograde and anterograde amnesia and impairment in the formation of new memory traces. The hippocampus is also involved in the formation and maintenance of cognitive maps and therefore in navigation tasks too.

Simultaneous examination of hippocampal neural population activity and the behavior of the test animal has shown correlation between electrical brain oscillations of different frequency intervals and behavior indicating that brain rhythms play a role in cognitive and memory processes. Thus experimental and theoretical examination of these brain oscillations are important for understanding both neural and higher level brain functioning.

## Specific aims

In the present Work I have analyzed the generating mechanisms of hippocampal theta and related gamma oscillations using computer models. Specifically, I aimed at identifying roles of different neurons and their ion channels, synapses in the generation of emergent population oscillation. I also tried to answer the question whether the hippocampus alone, only by its internal neural network structure and dynamics is able to generate synchronized, coherent theta and gamma oscillation.

## Methods

To answer my questions computer simulations of mathematical models of neurons and synapses were performed focusing on faithful reproduction of electro-physiological experiments while the model used was kept as close to biological reality as possible. These expectations are best met by the Hodgkin-Huxley formalism, which was adequately completed by necessary membrane currents to suite modeling purposes.

First, the population activity of a mutually and randomly interconnected interneuron network of the hippocampal CA3 region was studied using three types of depolarizing inputs: spatially homogeneous, time-independent stimulating current; spatially homogeneous, time-periodic stimulating current; and spatially inhomogeneous, time-periodic stimulating current. Output of these simulations were the membrane potential vs. time functions of each simulated interneuron, which were further analyzed for correlations as well as for population activity.

Second, a new model of the septum–hippocampal CA1 area consisting of septal GABAergic cells, alveus/oriens interneurons, basket cells and pyramidal cells was introduced partly based on detailed anatomical and neuro-physiological data from literature, partly based on results of electro-physiological experiments conducted by Dr. Mihály Hajós, researcher pharmacologist at Pfizer Inc. The model accounting for realistic anatomical connections between cell populations and—in the case of alveus/oriens interneurons and pyramidal cells—the hyperpolarization activated non-specific cation current was used to study rhythm generation in the septo-hippocampal system.

## Results

**T I.1** *Interneuron network of the hippocampal CA3 region was shown to be capable of generating robust, coherent gamma band oscillation and resonance to external phasic excitatory input*

**T I.2** *Taking into account finite axonal signal propagation time the gamma-frequency oscillation of the CA3 interneuron network was shown to become modulated in the theta frequency range*

**T I.3** *It was shown that firing properties of septal GABAergic cells are set by their position in the network and differences in membrane properties are not necessary to explain experimentally measured deviation of preferred firing phases of septal GABAergic cells*

**T I.4** *A mechanism—based on a detailed anatomical and physiological computer model of the hippocampus—is given to explain intra-hippocampal theta oscillation generation. The model is justified by preferential firing phases of neural populations relative to field theta oscillation matching those measured experimentally*

**T I.5** *An explanation was given to the necessary and contradictory role of hyperpolarization activated current and neural heterogeneity in intra-hippocampal theta oscillation generation*

**T I.6** *The hippocampal CA1 region was shown to be capable of generating theta-frequency modulated gamma rhythm. Furthermore, role of the basket cell network and the connection between basket cells and pyramidal cells in gamma rhythm generation was elaborated*

## Conclusions

Above results show that based on previous anatomical and physiological findings a neural mechanism can be given to explain generation of intra-hippocampal theta and gamma oscillations. Synchronizing forces (emergent synchronization in recurrent inhibitory neural networks; timing effect of hyperpolarization activated current) and neural heterogeneity or noise play and important role in the generation of oscillations with long period.

# Graph theoretical description of social networks

## Introduction and specific aims

Recently, there is a growing interest in networks present in several aspects of our everyday life. Their analysis has pointed out some common structural properties of several of these networks such as their power law degree distribution or small-world feature etc. Besides being scientifically interesting, many networks affect our everyday life creating an increasing demand from multiple perspectives for understanding their evolution and to explain why they show common properties.

A special case of the studied networks are those where nodes are human beings—termed social networks. Probably the most obvious feature of real networks that is missing from most of the models studied are characteristics of individual nodes in real networks which influence the connection probability. In the present Work I study effect of individual nodal traits on statistical structural properties of a new growing network model.

## Methods

Using formal analytical calculations and numerical, computer simulations two types of growing network models were studied. In the first case nodes of the network were identical, connections between them were formed uniformly and randomly. In the second case nodes had traits enabling to have different connection probabilities between different node types and thus creating a correlation in the network. Structure of the network was characterized by edge distribution of nodes and the cluster size distribution. The two types of networks were matched based on the average connection possibility and their structural properties were compared.

## Results

**T II.1** *Phase transition was shown in a new growing network model, i.e. a cluster of nodes with size proportional to the system size was shown to emerge as a function of connection probability and number of possible connection partners*

**T II.2** *Network growing mechanism was shown to set coarse-grained statistical structural properties of the network, while fine details are influenced by nodal traits*

## Conclusions

Knowing basic structural properties of networks one might forecast outcome of dynamical events taking place in these network (e.g. spread of opinion or infection among people or computers, search in a network, etc). The new growing network model presented in this Work elaborates on when a cohesive body of nodes including most of the system emerges, i.e. when one might observe a qualitative change in network properties. It also sheds light on that although general structural properties of the networks are set by the network growing mechanism, details important in both qualitative and quantitative respects—like precise parameters of the phase transition or the exact shape of the cluster distribution function—might also depend on nodal traits.

# List of publications

## Publications on the results of this Dissertation

- Orbán G, **Kiss T**, Lengyel M, Érdi P: Hippocampal rhythm generation: gamma related theta frequency resonance. Biological Cybernetics 84 (2001) 123–132
- **Kiss T**, Orbán G, Lengyel M, Érdi P: Intrahippocampal gamma and theta rhythm generation in a network model of inhibitory interneurons. Neurocomputing 38–40 (2001) 713-719
- Hajós M, WE Hoffmann, Orbán G, **Kiss T**, Érdi P: Modulation of septo-hippocampal theta activity by GABA$_{\text{A}}$ receptors: Experimental and computational approach. Neuroscience 126/3 (2004) 599–610
- Zalányi L, Csárdi G, **Kiss T**, Lengyel M, Warner R, Tobochnik J, Érdi P: Properties of a random attachment growing network. Physical Review E 68 066104 (2003)

## Other related publications

- **Kiss T**, Orbán G, Lengyel M, Érdi P: Hippocampal rhythm generation: gamma related theta frequency resonance. Cybernetics and System Research: 2000 (ed. Trappl R), Austrian Society for Cybernetic Studies, Vienna, (2000) 330–335
- Orbán G, **Kiss T**, WE Hoffmann, Érdi P, Hajós M: Modulation of Septo-hippocampal Theta Oscillation by GABA$_{\text{A}}$ Receptors: an Experimental and Computational Approach Program No. 679.11. 2003 Abstract Viewer/Itinerary Planner. Washington, DC: Society for Neuroscience, 2003. Online
- Érdi P, **Kiss T**: The Complexity of the Brain: Structural, Functional and Dynamic Modules. Emergent Neural Computational Architectures based on Neuroscience, (Eds. S. Wermter, J. Austin, D. Willshaw), Springer Heidelberg (2001)