## CURRENT RESEARCH TOPICS

### 1) Neural development

I am interested in different aspects of neural development. In particular, I am interested in mathematical modeling of the mechanisms employed by molecular circuits that control development. This type of approach is becoming more tractable due to tremendous experimental progress in recent years. As an example, recent experiments about the early cortical area specification and thalamo-cortical connectivity in the brain indicate that genetic factors are more important than neural activity (e.g. D. O'Leary group, Salk Inst., and E. Grove group, Univ. of Chicago, see: Science 288: 344 (2000); Science 294: 1071 (2001); Nature Neurosci. 6: 825 (2003)). The experimental data show that the Emx2, Pax6, and FGF8 proteins control the areas positioning and their perturbations lead to changes in cortical architecture/topography. I modeled (with some collaboration with G.B. Ermentrout, Univ. of Pittsburgh) these effects using a minimal circuit involving the above molecules. The model consists of the dynamics of thalamo-cortical axons modulated by signaling molecules that are regulated genetically, and by axonal competition for neocortical space (see, J. Comput. Neurosci. 17: 347-363 (2004)). The model is successful in generating cortical areas with sharp borders and in reproducing the results of area shifting experiments. It also makes some predictions and elucidates the mechanism of area multiplication in mammals that could be used by evolution. However, still many issues remain open. One of them is the mechanism of cortical map regeneration after ablation. An important question in this regard is the extent of this type of plasticity and what is the role of signaling molecules in this process? I am working currently on a mathematical model of this regeneration. This project is part of my broader interest in neuroanatomy and in uncovering principles of functional wiring in the brain (see, J. Comput. Neurosci. 15: 347-356 (2003); Phys. Rev. Lett. 86: 3674-3677 (2001)).

### 2) Genetic and neural basis of C. elegans locomotion

This project is in the Systems Biology category. I am interested in understanding the locomotory control in *C. elegans* worms. These worms have relatively simple nervous system composed of 302 neurons that has been fully characterized in terms of connectivity and morphology. *C. elegans* is also amenable to molecular and classical genetic studies. Additionally, their behavioral range is relatively small. All this make them a good system for studying neural aspects of behavior. Experimentally, it is known that many *C. elegans* mutants exhibit different locomotory sinusoidal patterns. However, despite the identification of hundreds of genes influencing locomotion in these worms, it is fair to say that the control of locomotion is poorly understood. In collaboration with a molecular biology lab of Dr. Sternberg (Caltech) I have been trying to develop a mathematical model of locomotion which takes into account both genetic and neural factors and that can be tested experimentally. Experimentalists in the lab are able to perturb genetically muscle function (myosin, unc-54 gene), motor neuron function (GABA, unc-25, unc-30, unc-46 genes), and some other functions. The model correctly predicts relationships (verified experimentally) between different parameters characterizing the motion such as velocity of propagation, velocity of muscular wave, frequency and amplitude of undulations. The model also explains how motor neurons in the ventral nerve cord control the movement through a feedback coming from muscles and mechano-sensory receptors. Two papers describing these topics are being submitted for publication.

**3) Dynamics of neural networks**

Connected networks of neurons exhibit many interesting dynamical patterns. It is believed that these patterns are related to the efficiency of information transfer between different brain regions. I have been interested in modeling such network states. One of them is synchrony in neural activities that may serve as a coincidence detection mechanism. In particular, I am interested in the interplay between synaptic plasticity and its influence on synchrony (see, Phys. Rev. E 65: 031902 (2002)). Another dynamical pattern which recently was experimentally revealed (in vitro), is the so-called critical state (Beggs and Plenz, J. Neurosci. 23: 11167 (2003)). This state is characterized by a balanced neural activity, in which some dynamic parameters exhibit unusual non-Poisson power-law statistics. I am trying to understand the mechanism of that peculiar behavior.

## RESEARCH PLANS

In general, my long-term research plan is to mathematically model molecular/cellular aspects of biological processes, and to study their influence on a phenotypic level.

I am going to continue my interests in the neural development of neocortical area specification. This is relatively new but hot field in experimental neurobiology. The number of experimental data is growing and that should help in constructing more precise models of cortical area specification and connectivity.

A closely related problem to the development of thalamo-cortical connectivity is reliable axonal guidance. In particular, I am planing to model mathematically molecular circuits responsible for axon guidance/cell migration. The specific questions, which I want to address are: (i) Which parts and features of the molecular circuit involving small GTPases, F-actin, microtubules and some other molecules are responsible for an external signal amplification. (ii) What features of this circuit are responsible for a robust axon/cell guidance even in the presence of strong noise in the external signal? (iii) What is the role of microtubule dynamic instability in this process?

Another interesting topic is synaptogenesis (see, e.g., Li and Sheng, Nature Rev. Mol. Cell Biol. 4: 833 (2003); Thomas and Huganir, Nature Rev. Neurosci. 5: 173 (2004)). Especially, I am interested in the process of synapse formation and maintenance. More and more experimental facts are becoming known about molecular mechanisms of this process, so I hope it will be shortly possible to approach that problem mathematically. This problem has potential implications for learning and memory. For example, there are experimental indications that MAPK and ERK signaling are involved in different types of synaptic plasticity (LTP and LTD). An interesting question in this regard is the nature of the interaction between these molecules and the state of neural electrical activity.

Apart from that, I would like to collaborate with experimental biologists, who have real interest in quantitatively understanding important biological systems. In this regard, I am open to any new interesting and challenging topics. I am looking for an institution that would foster such a collaboration, because I strongly believe that only combining theory with experiment can yield a high caliber science.

## TEACHING DESCRIPTION

Throughout my employment at various academic institutions, I have been teaching several courses both in physics and in mathematics. I enjoy teaching and have learned a lot about teaching methods in those institutions. I have a simple teaching philosophy, namely I try to illustrate the main idea in the beginning, and then I construct a mathematical formalism.

At Warsaw University, as a graduate student, I taught recitations in Quantum Mechanics for undergraduates in physics. I also taught a two-semester course in General Physics for undergraduate/graduate students in the Math Department. When I was a postdoctoral fellow in the Polish Academy of Sciences, I taught a one year course in Statistical Physics in the Center for Theoretical Physics. At Boston University, in the Center for BioDynamics, I had numerous opportunities for giving talks, on different subjects in computational neuroscience, during our weekly seminar. In my previous position, in the Department of Mathematics of the University of Pittsburgh, I taught three courses: two for undergraduates and one for graduate students. The courses for undergraduates were: Introduction to Linear Algebra/Matrices and a standard Calculus course. For graduate students I was teaching my own course (conceived by myself) about stochastic methods in science and engineering (stochastic differential equations). In this course, I presented basic notions of probability, distributions, averaging, correlation functions, Markov processes, as well as more advanced topics: Master equation, diffusion, the Fokker-Planck formalism, and stochastic differential equations. The aim of this course was to provide to graduate students tools which could be used in many practical problems of interdisciplinary character.

I have not been teaching at my current position in Caltech. However, I have regular (every few months) talks about my research progress during our lab meetings in the Division of Biology.