Project Proposal

The main theme of this research project is to harness the power of dynamical systems methods to gain insight into the activity of stimulus driven neuronal networks. During the past decades, scientists gained profound understanding of the mechanisms of single neurons, and anatomy of their connections. Nevertheless, the behavior of networks of these cells remains to be understood.

The study of dynamical patterns in neuronal networks relies greatly on computational and mathematical analysis. Single neuron (Hodgkin-Huxley type) models exhibit dynamics that are already so complex that it is difficult to predict what will happen when they are connected into networks. Moreover, the complexity and diversity of biological neuronal networks presents so many possibilities that a mathematical analysis is required to identify essential mechanisms. Dynamical systems tools both reduce and characterize complex systems, hence ideal for the task at hand.

For this project, I will apply my background in theoretical and applied dynamical systems to analyze neuronal networks regimes that are observed in the brain. I want to investigate the relation between synchronous and chaotic firing patterns and the meaning of transitions between these regimes. More specifically, I will study the effects of stimulus input in such networks. My research will be oriented toward two main goals: First, understanding the effects of a driving input, such as a prosthetic implant\(^1\)\(^2\), on the qualitative dynamical behavior of the network. Second, gaining insight in the encoding of sensory stimuli, linking this dynamical analysis to information theory.

Building on previous work, my first step will be to exploit the separation of timescales in the different components of the firing of an action potential, to reduce the coupled dynamics of neurons from a high to a low dimensional dynamical system. By carefully choosing the reduction, one can gain significant knowledge about the essential mechanisms in a given network. I will use this together with the computation of Lyapunov exponents to characterize chaotic behavior, as well as bifurcation theory tools to gain a novel representation of these models and transitions between dynamical regimes. What makes this approach powerful is that it is a mixture of analytical and computational methods. These methods have successfully been applied to the characterization of autonomous networks of neurons. For reference on the subject, see \[^3\]\[^4\]. The advancements of my proposed research lie in the inclusion of sensory or external inputs in the dynamics of such networks.

I also intend to collaborate with experimental and clinical researchers on related problems. A potential direction of my contributions would be to try and explain stimulus driven coherent dynamics observed in the EEG of human brains. Patients with neurological conditions resulting in excess of white matter (axonal connections) have enhanced coherence in certain frequencies but suppressed in others. My current advisor has discussed the possibility of collaboration with a laboratory at University of Washington on a project aiming at understanding the resulting neuronal dynamics in such patients under external inputs via rhythmic visual or auditory sensory stimulation.

\(^{1}\) Activity Patterns in a Model for the Subthalamopallidal Network of the Basal Ganglia ; D. Terman, J.E. Rubin, A.C. Yew, and C.J. Wilson ; The Journal of Neuroscience, April 1, 2002, 22(7): 2963-2976


\(^{4}\) We Got Rhythm : Dynamical Systems of the Nervous System, N. Kopell, Notices of the AMS, 2000, Vol.47, No.1, pp. 6-16