Quantitative Neuroscience

Mathematical models and computational methods have been very useful in understanding biological mechanisms underlying neuronal behavior. The Hodgkin-Huxley model, for example, has formed the basis for our understanding of how action potentials are generated and how they propagate along a nerve axon. More recently, mathematical models have been used to help understand cellular processes responsible for both normal and pathological firing patterns that arise in a wide range of neuronal systems. Examples include models for sleep rhythms, sensory processing, Parkinsonian tremor and working memory.

This course provides a detailed introduction to how mathematical and computational methods have been used to both develop and analyze models that arise in neuroscience. We begin by deriving the Hodgkin-Huxley model and then describe dynamical system methods for analyzing models. After discussing the dynamics of single neurons, we consider neuronal networks and describe how different types of population firing patterns depend on biological details, such as the intrinsic properties of individual neurons and synaptic coupling. We conclude by considering specific systems, including models for sleep rhythms, olfaction, working memory and neurological disease.

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Prerequisites: Math 152, 1152, 1157 or permission of instructor.

Text: Foundations of Mathematical Neuroscience
by G. Bard Ermentrout and David H. Terman

Quantitative Neuroscience

Catalog description: Introduction to mathematical modeling and computational analysis of neuronal systems, Hodgkin-Huxley model, dynamical systems methods, neuronal networks, models for neurological disease.

Purpose of course: This course provides an introduction to how mathematical and computational tools have been used to develop and analyze models that arise in neuroscience.

Textbook: Foundations of Mathematical Neuroscience by G. Bard Ermentrout and David H. Terman

Prerequisite: Math 152, 1152, 1157 or permission of instructor.

Grading: There will be 1 midterm (100 points), a final (200 points) and Semester Project (150 points).

Weekly Schedule:

1) Overview: Neurons, synapses, neuronal firing patterns
2) Hodgkin-Huxley Model: Resting potential, Nernst equation, Goldman-Hodgkin-Katz equation, Cable equation, action potential
3) Dynamics I: Introduction to differential equations; phase-planes; oscillations;
4) Dynamics II: Stability analysis, bifurcation theory, numerical methods
5) Single cell dynamics I: Propagating action potentials; rhythmic behavior;
6) Single cell dynamics II: Variety of channels, bursting oscillations; dendrites – multi-compartment models;
7) Synapses: Simple networks
8) Networks: Classification of network behavior; synchrony, role of different types of channels and coupling
9) Models for sleep: Sleep/wake cycle, Thalamocortical oscillations
10) Parkinson's disease: Basal ganglia, origin of pathological firing patterns, Deep brain stimulation
11) Olfaction
12) Vision
13) Stroke
14) Presentation of projects