Topics in Theoretical and Computational Neuroscience

MATH 6397
Lectures: MW 4-5:30 in 204AH

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Textbooks:

P. Dayan and L.F Abbott: **Theoretical Neuroscience**

H.R. Wilson: **Spikes, Decisions, and Actions**

H.C. Tuckwell: **Introduction to Theoretical Neurobiology**

A. Scott: **Neuroscience, A Mathematical Primer**

C. Koch and I. Segev, eds.: **Methods in Neuronal Modeling - 2nd Edition**

C. Koch: **Biophysics of Computation: Information Processing in Single Neurons**

W. Gerstner and W. Kistler: **Spiking Neuron Models**

I will also make use of the materials at Bard Ermentrout's website:

http://www.math.pitt.edu/~bard/classes/compneuro

General Remarks:

This course introduces students to standard mathematical models of individual neurons (Hodgkin-Huxley, 'integrate and fire', etc.) and the synaptic events by which neurons communicate. We will also spend some time discussing simple models of signal propagation along neurons. We will spend most of the first semester of the course learning about models of single neurons. If there is sufficient interest, there will be a second semester of the course which will deal with the modeling of neuronal networks.

The course is designed for advanced undergraduate and graduate students in mathematics, physics, engineering and the biological sciences and will be centered on differential equation models of neurons. Applications of information theory and other statistical techniques to neural encoding and decoding will be covered at at the end of the first semester (time permitting).

Computers:

The software package XPP (available at **http://www.math.pitt.edu/~bard/xpp/xpp.html)** will be used for all simulations which will be assigned as homework. This is a free package with versions that run under UNIX and Windows. I strongly suggest that you install this software on your personal computer. XPP is also installed on the computers in the Mathematics Computer Lab. These computers will be accessible during the week, and I will ask for an account to be created for everybody who needs one.

Please arrange to have some access to XPP by the end of the first week in order to finish the first assignment.

Do not send email to Bard Ermentrout about any problems with this software without asking your systems administrator, computer tech, or myself first. In particular he does not maintain the Windows version actively (I have checked it with several versions of Windows, and it works fine). Also there are several X-windows emulators that you can use to run the UNIX version of XPP (see Prof. Ermentrout's page for details).

Prerequisites:

The only prerequisite is a course on differential equations, such as MATH 3331. I will spend the first week on reviewing topics from the qualitative theory of differential equations.

How to get in touch with me:

The best way to get in touch with me is by e-mail. Use it if you have a question that can be answered quickly, or need to set up an appointment to see me outside of my office hours.

Homework:

There will be 7 homework assignments during the semester. Each assignment will be due approximately two weeks after it was assigned. You are free to work together, however the work you turn in must be your own. In other words you are encouraged to work together on solving the problems, but not simply copy the solutions from other students. You also must each run your own simulations. It is best that you write up the solutions on your own, and not in a group.

Each homework set will be worth 10% of your grade.

Final Project:

In addition to the homework there will be a final project for the class. This will be a project on a topic of your choice. The only requirement is that the project involves theoretical and computational neuroscience. I will be glad to provide suggestions, but feel free to look through the textbooks above for topics that I will not cover in class. If you are currently doing research in neuroscience, feel free to present your work.

You will work on the projects in teams of 2 or 3. Each team will give a 25 minute presentation on this topic during the last class period and during the time that is scheduled for the final.

You will need to submit a topic for your presentation by October 20

Attendance:

Attendance is strongly encouraged.

Grades:

Grades will be assigned on the following basis:

70%	homework
30%	final project

Academic Honesty:

Dishonesty includes cheating on your homework, falsifying data, and misrepresenting the work of others as your own (plagiarism). I will take all instances of academic dishonesty very seriously. I urge you to read the sections of the student handbook discussing academic dishonesty and the disciplinary actions it entails.

List of Topics Covered:

1. Review of certain aspects of differential equations theory. The examples discussed will come for Wilson's book. **The assignment for this week is to install XPP, and complete the first part of the XPP tutorial which comes with the program, and is also available at**

http://www.math.pitt.edu/~bard/xpp/xpp.html

2. Passive properties of neurons. The deterministic integrate and fire model of a neuron.

3. Cable theory: derivation of the cable equation, linear cable theory, solving the cable equation with different boundary conditions, equivalent cylinders.

4. Modeling channel dynamics: the Nernst equation, the Goldman formula, various channel models including stochastic models.

5. The Hodgkin-Huxley model: putting together the channels, preliminary analysis of the one compartment model.

6. Reduction of higher dimensional systems and phase plane analysis of various two dimensional models of excitable systems. Analysis of bursting models using bifurcation theory and singular perturbation theory.

7. The full Hodgkin-Huxley and FitzHugh-Nagumo. Traveling waves and pulses. Further uses of singular perturbation theory.

8. Compartment models.

9. Noise in models of single neurons. The noisy integrate and fire neuron and stochastic resonance.

10. Neural Encoding and Decoding. Firing rates and spike statistics, information theoretic approaches: entropy and mutual information