Syllabus: Computational Neuroscience

BIOL 378/478
MATH 378/478
COGS 378
NEUR/EBME/EECS 478

Spring 2017
updated January 22, 2017

Course Description:

Computer simulations and mathematical analysis of neurons and neural circuits, and the computational properties of nervous systems. Students are taught a range of models for neurons and neural circuits, and are asked to implement and explore the computational and dynamic properties of these models. The course introduces students to dynamical systems theory for the analysis of neurons and neural circuits, as well as to cable theory, passive and active compartmental modeling, numerical integration methods, models of plasticity and learning, models of brain systems, and their relationship to artificial neural networks. Term project required. Recommended prerequisites: multivariate calculus (MATH 223) and a first course in differential equations (either MATH 224 or the sequence BIOL 300 and BIOL 306). Cross-listed as BIOL 378/478, MATH 378/478, COGS 378, EECS 478, EBME 478, NEUR 478. Students enrolled in MATH 478 will make arrangements with the instructor to attend additional lectures and complete additional assignments addressing mathematical topics related to the course. Consent of department required.

Instructor:

Peter Thomas, Associate Professor
Primary Appointment: Mathematics, Applied Mathematics, and Statistics
Secondary Appointments: Biology. Cognitive Science. Electrical Engineering and Computer Science.
pjthomas--at--case.edu / 216-368-3623
Office: 212 Yost Hall
Office hours: (MWF 8:30-9:20 am), and by appointment. *Please let me know if you plan to come by, as other meetings come up occasionally at these times.*
Course meeting: MWF 10:35-11:25 a.m.
Location: Bingham 204.

Course Requirements:

1. Preparation, attendance, participation.
2. Regular problem sets.
3. Term project.

The term project will involve developing, implementing and analyzing the behavior of a model for a neural system of interest to the student (subject to consultation with and approval of the instructor). In most cases, students will begin by reimplementing a model available on the ModelDB database (https://senselab.med.yale.edu/modeldb/), preferably implemented in either Matlab, NEURON or XPP. Before spring break, students should have identified a model they wish to work with, read the associated papers, and run the model themselves to reproduce (some or all of) the figures from the paper. *Project proposals will be due before Spring Break*, and should include a statement of one or more specific aims, a background and significance section, a methods section describing the analytic and/or computational techniques proposed to be employed, and an "expected results" section describing the general form the results are expected to take and describing the kinds of data analysis to be applied to interpreting them. The proposal should not exceed three pages. The project writeup will be due in early April, to allow time for revision and resubmission if necessary. Depending on class size and available time, students may be required to present brief oral presentations of their research project to the class.

Students enrolled for graduate credit (under a 478 cross-listing) will have additional expectations including (i) an additional 10-15 minute presentation on a research topic, and (ii) additional homework problems at a higher mathematical or conceptual level. Students enrolled in a 378 listing are required to work on their projects in teams of two; students enrolled in a 478 listing may work in a team of two or individually. Each student must write up and submit their project individually. Write-ups resulting from team projects should include a statement indicating which student was responsible for which technical contributions (coding, calculations, literature review, etc.).

Grades will be based on (1) general participation and preparation (10%), (2) homework (50%), (3) term project (40%). There will be no exams.

Required Textbooks:

There will be one required textbooks for the course available in the bookstore, a second available (for free) online, and additional recommended texts.

1. *Mathematics for Neuroscientists* (Fabrizio Gabbiani and Steven J. Cox): required text.

Some readings and exercises may be based on the following book (made freely available online courtesy of the author):

2. *Spikes, Decisions and Actions* (Hugh R. Wilson).

http://cvr.yorku.ca/webpages/wilson.htm#book

A collection of *MATLAB* scripts accompanies the text.

3. For students enrolled in MATH 478 there will be additional readings and assignments from *Mathematical Foundations of Neuroscience* (Ermentrout and Terman).

4. While not required, it is recommended that students have access to

4a. *Simulating, Analyzing, and Animating Dynamical Systems* (Ermentrout). This book serves as an introduction to computer simulation and analysis of dynamical systems, and an intro to XPP/AUTO.

4b. *The NEURON Book* (Ted Carnevale and Michael Hines). Additional NEURON resources are available at http://www.neuron.yale.edu/neuron/

Course Resources Online:

There will be additional articles recommended or required for the course. The reading list as well as homework assignments will be posted on the course google docs page

https://drive.google.com/drive/folders/0B-JMPWjMi0mscU9JSmpLc0EwWDQ?usp=sharing

and/or the university's Canvas system.

Software:

A significant part of the course will involve implementing computational models of neurons and neural networks. A variety of platforms are available for this purpose, each with its own strengths and weaknesses. We will focus on *Matlab*, which is the basis of many exercises in Gabbiani and Cox's book, as well as a suite of scripts written by Hugh Wilson to accompany *Spikes, Decisions and Actions*. In addition, *The NEURON simulation environment* is a collection of software tools specialized for biophysically realistic simulations of single compartment and multi-compartment nerve cells and networks of nerve cells. *XPP*, developed by mathematical neuroscientist B. Ermentrout at the University of Pittsburgh, is a tool for phase plane analysis of dynamical systems, particularly suited for analysis of model neural systems and their bifurcations. NEURON and XPP will be used from time to time for demonstrations (and possibly exercises), and may be useful for your course project. I recommend installing them on your machine prior to the start of the course.

Matlab is available via CWRU site-license from https://software.case.edu/.
NEURON is freely available from http://www.neuron.yale.edu/neuron/.
XPP is freely available from http://www.math.pitt.edu/~bard/xpp/xpp.html.

Additional Recommended Textbooks:

Neuronal Dynamics (Wulfram Gerstner, Werner M. Kistler, Richard Naud and Liam Paninski). This text includes numerous demos implemented in python with source code available at (http://neuronaldynamics.epfl.ch)

Dynamical Systems in Neuroscience (Eugene Izhikevich). An excellent introduction to single-cell physiology from a dynamical systems point of view. Part of the book is available from the author's website (http://www.izhikevich.org/publications/dsn/index.htm)

Biophysics of Computation (Koch). A unified presentation of computational neuroscience including many of the mathematical modeling topics covered. Has been used as a text for this course in the past.

Methods in Neuronal Modeling (Koch & Segev). A classic collection of reviews of different computational neuroscience topics. Has been used as a text for this course in the past.

Theoretical Neuroscience (Dayan & Abbott). An undergraduate textbook covering many of the topics in this course.

Nerve, Muscle & Synapse (Katz). A classic, and relatively brief, introduction to neurophysiology.

Neurophysiology (Johnston & Wu). A standard reference on neurophysiology.

Principles of Neural Science (Kandel, Schwartz and Jessell). A comprehensive (non-mathematical) text on all aspects of neuroscience.

Nonlinear Dynamics and Chaos (Strogatz). A very readable primer on applied differential equations.

Elements of Applied Bifurcation Theory (Kuznetsov). An advanced mathematical book on bifurcation theory.

Course topics & schedule

We will tentatively plan to explore the following topics, following a selection from Gabbiani & Koch (roughly chapters 2-6, 8-12, 14-17, 20-21, 27), occasionally supplemented by additional readings and exercises. Topics will include electrophysiology of nerve cells, Hodgkin & Huxley's model for the action potential, analysis of model neurons as dynamical systems, conductance based neural models, simplified neural models, synchronization of coupled model cells, quantification of spike train variability, model reduction, firing rate codes and early vision, simple and complex cells in visual cortex, and neuronal networks. See the course schedule for updates, and reading assignments.

Graduate students desiring further in-depth study of
computational neuroscience should consider applying to the
Woods Hole Marine Biological Laboratory
Special Topics Summer Course on
Methods in Computational Neuroscience
(July 30 – August 25, 2017; Applications due March 7, 2015):

http://www.mbl.edu/mcn/
