Syllabus: Computational Neuroscience

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

Spring 2008

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 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, Asst. Prof. of Mathematics, Biology & Cognitive Science
pjthomas--at--case.edu / 216-368-3623
Office hours: Tues & Thurs 2:45-4:15 or by appointment
Course meeting: Tues & Thurs 1:15-2:30
Location: Crawford 618.
Teaching

Course Requirements:

1. Attendance, preparation, participation.
2. Biweekly problem sets.
3. Term project.

Homework sets will be graded in difficulty, to accommodate differences in the background assumed for students in different programs. Students enrolled in BIOL/COGS 378 will be expected to complete a subset of the homework problems (indicated by "*" on the assignment). Students enrolled in BIOL/NEUR/EBME/EECS 478 or MATH 378 will be expected to complete additional problems (denoted by "**"). Students enrolled in MATH 478 will be expected to complete additional problems (denoted by "***"). Some adjustments to these expectations may be made by consultation in advance with the instructor.

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). Project proposals will be due before Spring Break, and should take the form of a brief research grant proposal including a summary with 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 making sense of them. The project itself 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 make brief oral presentations of their research project to the class. Students who wish to form teams (no more than two per team) should petition the instructor well in advance of the proposal deadline.

The grades will be based on (1) general participation and preparation (5%), (2) homework (50%), (3) term project (initial proposal, 10%; presentation, 10%; final report; 25%). There will be no exams.

Required Textbook:

Dynamical Systems in Neuroscience (E. Izhikevich, "Izh"). Author's website: http://vesicle.nsi.edu/users/izhikevich/publications/dsn/index.htm

Software:

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

Recommended Textbooks:

The NEURON Book (Carnevale & Hines). (Strongly recommended).

Biophysics of Computation (Koch).
Methods in Neuronal Modeling (Koch & Segev).
Spikes, Decisions and Actions (Wilson).
Theoretical Neuroscience (Dayan & Abbott).
Nerve, Muscle & Synapse (Katz).
Neurophysiology (Johnston & Wu).
Elements of Applied Bifurcation Theory (Kuznetsov).
Nonlinear Dynamics and Chaos (Strogatz).

Course topics & schedule (provisional)

Week 1.
Introduction to Neural Modeling. (Izh Chapter 1). Introduction to the NEURON simulation environment. (The NEURON Book Chapter 1).

Week 2.
Electrophysiology of Neurons. Nernst potential, ions & conductances, equivalent circuit. The Hodgkin-Huxley model. (Izh Chapter 2).

Week 3.
Dynamical systems in one dimension. Phase portraits. Electrophysiological examples. (Izh Chapter 3).

Week 4.
Planar dynamical systems. Limit cycles, oscillators, stability, phase portraits. (Izh Chapter 4).

Week 5.
Conductance-based models. Reduction of multidimensional models. (Izh Chapter 5).

Week 6.
Bifurcation analysis. (Izh Chapter 6).

Week 7.
Neuronal Excitability. Integrators versus resonators. (Izh Chapter 7).
Project Proposals Due.

Week 8.
A gallery of simplified models. (Izh Chapter 8).

[SPRING BREAK]

Week 9.
The geometry of bursting. Bursts and information processing. (Izh Chapter 9).

Week 10.
Synchronization. Phase oscillators. Phase resetting curves. Resonance and Arnol'd tongues. (Izh Chapter 10).

Week 11.
Student Talks on Term Projects

Week 12.
Network models. Memory and pattern classification. The perceptron. Backpropagation neural networks. Hopfield network. Kohonen's self-organizing map.
(Selected readings).
Alternative: continue with synchronization, noisy resetting curves.

Term papers due.

Week 13.
Models of the visual pathway: receptive fields, lateral inhibition, orientation tuning, cortical maps. (Selected readings).

Week 14.
Pattern formation. Hallucinations. Cortical map formation.
(Selected readings).
Revised term papers due (if needed).

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
(Aug 3-31, 2008; Applications due March 10, 2008):
http://www.mbl.edu/education/courses/special_topics/mcn.html
