Syllabus for Computational Neuroscience

Crosslistings:
BIOL/COGS/MATH 378 and BIOL/CSDS/EBME/ECSE/MATH/NEUR 478

Instructor: Peter Thomas
Department of Mathematics, Applied Mathematics, and Statistics
Yost Hall 212

Spring Semester 2021

Catalog 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, CSDS 478, EBME 478, ECSE 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.

Course Goals

The broad goal of the course is to empower students to build and analyze biophysically grounded mathematical and computational models of neural systems. The instructor aspires to provide effective professional preparation for the next generation of computational neuroscientists.

Instructor & Logistics

Peter Thomas (he/him/his), Professor
Primary Appointment: Mathematics, Applied Mathematics, and Statistics

Secondary Appointments: Biology. Cognitive Science. Computer & Data Science. Electrical, Control & Systems Engineering.
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Office: 212 Yost Hall[1]
Office hours: TBD.
Course meeting: Tuesdays & Thursdays 8:30 a.m. – 9:45 a.m. (US Eastern Time Zone)
MATH 478 will have additional meetings Fridays 8:30 a.m. – 9:30 a.m. (US Eastern Time Zone) to discuss mathematical aspects of the course in greater depth.
Mode of instruction: Class will be held synchronously via zoom. Students will be e-mailed an invitation, and should also be able to access class through Canvas. Email Note: Please include one of the terms: BIOL 378, BIOL 478, MATH 378, MATH 478, COGS 378, EBME 478, et cetera, in the subject line when writing to the instructor. This decreases the chance I will overlook your message.

Course Requirements:

1. Preparation, attendance, participation.
2. Regular problem sets.
3. Short research presentation (graduate students only).
4. Term project, paper & presentation.

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 should begin by reimplementing a model available on the ModelDB database (https://senselab.med.yale.edu/modeldb/), preferably implemented in either Matlab, NEURON, XPP, or SNNAP. Because CWRU has a truncated semester, students should begin looking through ModelDB as soon as the course begins in search of a model they would like to work with.[2] Project proposals will be due on Feb. 25, 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 you propose to employ, and an "expected results" section describing the general form you expect the results to take, and describing the kinds of data analysis you plan to apply to interpreting them. The proposal should not exceed three pages. The project writeup will be due in early April, to allow time for revision if necessary. In lieu of a final exam, students will 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 of their choice, 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, at the instructors discretion. Whether working alone or

[1] The instructor will not be holding in-person office hours during the spring 2021 semester.
[2] For students looking for explicit suggestions: Models 116123, 152292, and 257608 use XPP; models 3511, 93326, and 232876 use NEURON, and models 49305, 116945, and 266871 use Matlab.

in a team, each student must write up and submit their project individually. Write-ups resulting from team projects must include a statement indicating which student was responsible for which specific 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.

Academic Integrity

The instructor would like to encourage students to collaborate on solving homework problems; at the same time, please keep in mind that all work you turn in must be your own. Thus, your collaborations should stop at the point where you begin the final writeup of an assignment. If an assignment involves writing computer code or working through a computer exercise, you should do so on your own. As in any scholarly work, when you do obtain outside help you must acknowledge it. (*E.g.* "by using the orthogonality of the eigenvectors (suggested by Jane Student), we can establish that ..."; when writing computer code you can use comments to indicate *e.g.* "this algorithm occurred to me while discussing the problem with Joe Student" where appropriate.) Such an acknowledgment will never lower your grade; it is required as a simple matter of intellectual fairness.[3]

For more information on the University's ethics policy, please consult `http://studentaffairs.case.edu/handbook/policy/ethics.html`.

Final Exam Slot

The scheduled final exam slot for this class is 12:00 – 3:00 p.m., Monday, May 17, 2021. In lieu of a written final exam, we will use this time for term project final presentations. All students should plan to attend these presentations, unless you live in a time zone outside of GMT-8 (US Pacific) to GMT+1 (Europe).

Required Textbooks

There will be one required textbook for the course, available (in electronic form) from the university bookstore, a second available (for free) online, and additional recommended texts.

1. Mathematics for Neuroscientists (Fabrizio Gabbiani and Steven J. Cox), 2nd edition (required text). The book has a publisher website.

[3] I adapted this paragraph from a similar one in the Fall 2004 syllabus of Physics 110 by Professor D. Styer, of Oberlin College, whom I hereby acknowledge.

There is also a companion site with links to matlab code developed by the authors.

2. For students enrolled in MATH 478 there will be additional readings and assignments from Mathematical Foundations of Neuroscience (by Ermentrout and Terman). This book is available from SpringerLink.

The following books are recommended, but not required

- 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, which we will use in the course.
- The NEURON Book (Ted Carnevale and Michael Hines). This book is both an introduction to the mechanics of using the NEURON simulation environment (which we will use in the course) and a conceptual introduction to modeling. 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 through Canvas.

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 make use of Matlab, which is the basis of many exercises in Gabbiani and Cox's book. 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. NEURON has become increasingly integrated with python, and we will use the two together for part of the course. Finally, XPP, developed by mathematical neuroscientist Bard 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/python and XPP will be used from time to time for demonstrations (and some 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 CWRU's software center. NEURON is freely available from http://www.neuron.yale.edu/neuron/. XPP is freely available from Bard Ermentrout's website. Additional information about these software platforms will be made available through the course canvas site.

Finally, CWRU's virtual desktop initiative is testing a VD environment for this course. My logging in to MyApps.case.edu you should be able to navigate to a "Computational Neuroscience" desktop on which python (and jupyter notebooks), NEURON, XPP and Matlab are already installed and ready to go on a virtual machine.

Course topics & schedule

We will tentatively plan to explore the following topics, following a selection from Gabbiani & Koch (roughly chapters 2-9, 11-13, 17, 21-23, 25-26, 30), occasionally supplemented by additional readings and exercises. T opics will include a selection of the following: 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, central pattern generators, quantification of spike train variability, model reduction, firing rate codes and early vision, simple and complex cells in visual cortex, and neuronal networks. The instructor will post a detailed schedule of readings and assignments on Canvas.

Special considerations concerning remote instruction

We will be conducting class by zoom. As the instructor recently returned from a long sabbatical to find the world of higher education in general disarray, he is working hard to catch up with all this new-fangled technology (canvas, zoom, echo360) and will be grateful for your forbearance when snags inevitably crop up.

No-class day

There will be no class held on Tuesday, March 16. The instructor will be available at the usual class time for extended office hours, project consultation, etc.

Late grading policy

The Dean of Students has urged faculty to find ways to relieve pressure on students, on account of the unusual stress wrought by remote instruction and the Covid-19 pandemic. Unfortunately, there are no shortcuts to mastering computational neuroscience (or any other subject) that avoid sustained efforts at reading, researching, and problem solving. The usual grading policy for this course is as follows: if an assignment would have been worth Q_0 points, had it been submitted on time, then it will be instead worth $Q(t) = e^{-t/\tau}Q_0$ points if it is t days late (with t rounded up to the next largest integer). During normal times $\tau = 7$, so that an assignment that is one day late is worth $e^{-1/7} \approx 86.7\%$ of what it would have been on time, and an assignment that is one week late is worth $e^{-7/7} \approx 36.8\%$ of its full value. The problem with granting long extensions is that new work gets assigned while old work remains unfinished, compounding student stress. However, in light of the Dean's (justified) concerns about student anxiety levels, I will triple τ to 21. So now a three-day-late assignment will still be worth about 86.7% of an on-time assignment, and so on. (A one-day-late assignment will be worth $e^{-1/21} \approx 95.4\%$ of on-time.) This change will probably cause a headache for the grader (who is also a student, subject to worrisome levels of stress); in any case it will be in the best interests of all if you are able to keep up with the class on schedule.

Contingency plans

In case zoom crashes, we will attempt to move to

1. Jitsi: (`https://meet.jit.si/CWRU-Computational-Neuroscience-2021`)
2. or, if that doesn't work: Google hangouts (`https://meet.google.com/rjv-fgxx-shv`)

In the event that the instructor's internet connection is interrupted, there will be one or more students designated in advance as meeting co-hosts so that the class session can continue until the instructor can return. In case this happens, here are some contingencies:

1. If a student is giving a presentation, they should continue the presentation. All classes are set to be automatically recorded, so the instructor can go back and review anything he missed.
2. If the instructor is lecturing when cut off, the class is welcome to enter a discussion focused on solving problems in the next homework set (for example) until the instructor can rejoin.
3. If the instructor is guiding the class through an online tutorial, or if the class is working together in small groups, then the class should continue in this way until the instructor can rejoin.

The Do's and Donts of Remote Video Learning

Here are some reminders taken from UTech's Netiquette Refresher document.

- Do stay connected to the course during the entire Zoom session.
- Do always have video camera on so everyone is visible; turn camera off only during breaks.
- Do mute your microphones when others are talking to eliminate background noise.
- Do act as though you are in a real class and remember that you are always on camera; make eye contact with the camera while talking, be a good listener when others are speaking, dress appropriately, and use appropriate language.
- Dont eat during class unless your professor has indicated it is ok.[4]

[4] We'll see how this goes. Since class is at 8:30 am Eastern, you can bring your morning coffee etc. Be as discrete as if you were in the front row of the class (because you are!).

- Do raise your hand if you want to speak.[5]
- Do ALWAYS log on prior to the beginning of class to allow time to troubleshoot potential connection issues.
- Do contact help desk for technical difficulties at Phone 216-368-4357; Email: help@case.edu Live Chat help: https://case.edu/utech/help
- Do email your professor immediately if you have technical difficulties during class.
- Don't allow others (visitors, family, friends or other distractions) near your work area during class.
- Do turn off your cell phones during class. The only time it is appropriate to be on the phone is if you are talking with tech support.
- Don't access email, read unrelated materials or use Instant Messaging during class. Use only classroom? designated programs/applications during class.
- Do let your professor know well in advance if you may need to be late or miss class or need to leave class early. Each professor has different opinions regarding class attendance so never assume your absence will be excused.[6]
- Don't leave the room unless absolutely necessary, and keep your head centered in the camera at all times.
- NOTES: No private chats will be allowed during class or seminar. This is to create a respectful, civil environment for all participants without distracting side conversations. Remember that the Case Western Reserve University Academic Integrity Policy and the Student Code of Conduct apply to all remote learning, assignments, testing, and behavior. Sessions may be recorded only for purposes of learning in a specific course. Downloading or replicating a recording and using it inappropriately will be addressed as a university student conduct violation.

Further Bibliography

For students wishing to pursue a broader and deeper introduction to computational neuroscience, these textbooks complement those used in the course.

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.

[5] You can raise your hand in front of your camera, use the "raise hand" feature under the participants tab, put a question in the chat, or (if none of these gets the instructor's attention in a reasonable time) unmute and speak up.

[6] Note attendance and participation is part of the grade for the course.

Spikes, Decisions and Actions (Hugh R. Wilson) gives an overview of dynamical systems concepts useful for getting started in neuroscience. The author provides a collection of Matlab scripts accompanying the text.

An Introductory Course in Computational Neuroscience (Paul Miller). This book presumes less background in calculus and differential equations than the course does, and is more focused on computational implementations. It covers an excellent range of topics and is ideal for biologists easing their way into the subject.

Biophysics of Computation (Koch). A classic, 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). Another classic. This text gathers a 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, from a biological point of view.

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: With Applications To Physics, Biology, Chemistry, And Engineering (Strogatz). A very readable primer on applied differential equations.

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

Course Announcement

Graduate students desiring further in-depth study of computational neuroscience should consider applying to the

Woods Hole Marine Biological Laboratory
Summer Course on Methods in Computational Neuroscience
(August 1 – August 27, 2021)
http://www.mbl.edu/mcn/