Brandeis UNIVERSITY

NBIO136b Computational Neuroscience

How can neurons in our brain produce spikes of electrical activity? How do the neurons communicate with each other? How do groups of neurons act in concert to produce the mental activity so important to our lives? If you have thought about these questions and want more than a hand-waving answer, then computational neuroscience is the course for you.

A rigorous understanding of any process requires us to be able to formulate the process in terms of mathematical equations. When a process is as complex as the voltage dynamics of a single-cell and even more so the coherent operation of many such cells in our brain, we must both simplify the underlying mathematical description and use a computer simulation to test the mathematical equations properly describe the behavior. In this course, you will learn these skills, which in principle can be generalized to studies of any complex system.

Contact Details

Instructor: Paul Miller Office location: Volen 317 (via Volen 316)
Email: pmiller@brandeis.edu, zoom link : see below under 'Continuity'

TA : Fox Gourianova Office location: Volen 201
Email: gourianova@brandeis.edu, zoom link : https://brandeis.zoom.us/j/3436670357

Communication
Please contact by email.

Continuity
If it becomes impossible to complete in-person classes, continuation will continue via Zoom. The link is: https://brandeis.zoom.us/j/95684927593?pwd=Z0FzaVpSb1AyK2FrYTg4MVV2MGlCdz09 Pwd: 260644
Communication of class changes will be via Moodle email announcements.

Meeting Times/Locations

Classes
Tuesday/Thursday, 3:55 – 5:15 PM Gerstenzang 124
Computer Tutorials
Thu Jan 16 5-7:30pm, Sun Jan 19 6:30-9pm Goldfarb 230 (Computer classroom)
Student Hours
For questions or extra help, after you have spent over 10 mins yourself on figuring it out:
Paul Miller Monday 1:15-2:15 PM in office;
Wednesday 9:30-10:30 AM by zoom
Fox Gourianova Thursday 9-11 AM

Accommodations

Brandeis seeks to create a learning environment that is welcoming and inclusive of all students, and I want to support you in your learning. If you think you may require disability accommodations, you will need to work with Student Accessibility Support (SAS) (781-736-3470, access@brandeis.edu). You can find helpful student FAQs and other resources on the SAS website, including guidance on how to know whether you might be eligible for support from SAS. If you already have an accommodation letter from SAS, please provide me with a copy as soon as you can so that I can ensure effective implementation of accommodations for this class. In order to coordinate exam accommodations, ideally you should provide the accommodation letter at least 48 hours before an exam.

Course Description

Course Prerequisite(s):
Students should have taken a course in calculus and at least one course of the following: Principles of Neuroscience (NBIO140b) or Electricity and Magnetism (PHYS 10b/11b/15b) or a computer science course such that you are comfortable writing a computer code that solves some sort of problem. While the necessary topics from these courses are briefly covered in NBIO136, if they are all new to you it is unlikely you will be able to keep up. Chapter 1 of the textbook posted in LATTE covers the foundational material, with a focus on background mathematics and an introduction to coding in either Python or MATLAB. I strongly recommend you read as much of the Chapter as you can to see what areas you can brush up on, and **start working through the Python tutorial before the class if you are new to coding**. There will be two optional coding tutorials in the first week of class to help those who are new to it.

Learning Goals:
After taking this course you should be able to simulate model neurons and circuits and analyze basic spike train data. More generally you should gain the ability to produce a simple model of a dynamical biological system with appropriate differential equations, to write a computer code that will solve the model through time and interpret the meaning and relevance of the resulting outputs.

Within this course you will learn about:

Single cell models – how does a neuron work (and produce spikes) and how can we model it? Models range in complexity as more channels or conductance variables are added to a model neuron and/or more spatial complexity is added.

Small circuits – if 2 or more neurons are connected by a synapse, we model the synaptic interaction. The coordinated behavior of just 2 neurons can be qualitatively different from one alone. Small circuits are usually modeled with more realistic single-cell models and synapses.

Large circuits – tens to thousands of model cells, often aimed at producing behavior that matches either neural measurements in animals or can lead to intelligent behavior. Level of modeling ranges from simple models of spiking neurons to “firing-rate” models similar to those used in artificial neural networks.

Plasticity – the term used for changes in synapses connecting neurons, or the neurons themselves. Plasticity is essential for learning and long-term memory.

Spike train analysis – when spike times are recorded, what information can we derive from them?

Credit Hours:
Success in this four-credit course is based on the expectation that students will spend a minimum of nine hours of study time per week outside of class, including reading and commenting on the course material before class, completing tutorials not finished within class, and reviewing material in preparation for exams.

The class is “half-flipped” with 50% presentation by the professor and 50% in-class tutorials. Required readings to gain course content will be done by students before each class. Students will comment or ask/answer questions on the readings and gain credit for doing so before each class

Course Plan

Jan 14	Introduction to course, Python, and differential equations. (Ch. 1, Sect. 1.4-1.5)	
Jan 16	*The leaky integrate-and-fire model (Tutorial 2.1, Ch. 2)	
Jan 23	Modeling the refractory period (Tutorial 2.2, Ch. 2)	
Jan 28	*Extensions of the LIF model (Tutorial 2.3, Ch. 2)	**2.1 due**
Jan 30	Generating receptive fields with spike-triggered averages (Tutorial 3.1, Ch. 3)	
Feb 4	*Statistical properties of simulated spike trains (Tutorial 3.2, Ch. 3)	**2.3 due**
Feb 6	Receiver-operating characteristic of a noisy neuron (Tutorial 3.3, Ch. 3)	
Feb 11	*The Hodgkin-Huxley model (Tutorial 4.1, Ch. 4)	**3.2 due**
Feb 13	Post-inhibitory rebound (Tutorial 4.2, Ch. 4)	
Feb 25	*2-compartment model of a bursting neuron (Tutorial 4.3, Ch. 4)	**4.1 due**
Feb 27	Synaptic responses to changes in inputs (Tutorial 5.1, Ch. 5)	
Mar 4	Detecting circuit structure in a connectivity matrix (Tutorial 5.2, Ch. 5)	**4.3 due**
Mar 6	*Bistability and oscillations from two LIF neurons (Tutorial 5.3, Ch. 5)	
Mar 11	MIDTERM	
Mar 13	Review and Bistability	
Mar 18	Bistability and oscillations in a firing-rate model with feedback (Tutorial 6.1, Ch. 6)	
Mar 20	*Frequency of coupled unit "PING" oscillator (Tutorial 6.3, Ch. 6)	**5.3 due**
Mar 25	Two dynamical modes of a decision-making circuit (Tutorial 6.2, Ch. 6)	
Mar 27	*Orientation selectivity in a ring model (Tutorial 6.4, Ch. 6)	**6.3 due**
Apr 1	The inhibition-stabilized circuit (Tutorial 7.1, Ch. 7)	
Apr 3	*Diverse behaviors of similar circuit architectures (Tutorial 7.2, Ch. 7)	**6.4 due**
Apr 8	Pattern completion and pattern separation by Hebbian learning (Tutorial 8.1, Ch. 8)	
Apr 10	*Competition via STDP (Tutorial 8.2, Ch. 8)	**7.2 due**
Apr 22	Learning the weather-prediction task in a neural circuit (Tutorial 8.3, Ch. 8)	
Apr 24	*Principal Component Analysis (Tutorial 9.1, Ch. 9)	**8.2 due**
Apr 29	A model of eye-blink conditioning (Tutorial 8.4, Ch. 8)	
May 1		**9.1 due**

* = tutorial for students to complete over the class indicated and the next one, due before class on day indicated.

Course Requirements

Attendance

Attendance is expected unless I agree to a reasonable reason for absence. In the unlikely event that we need to have zoom meetings then cameras should be on.

Assignments

The course will contain 11 computer tutorials. Each Tutorial is scored out of 20, with 2pts deducted per day late until a score of 10 is reached. Half of points lost for other than lateness can be regained by redoing the tutorial.

The best 9 of 11 will count toward the final grade, but students are expected to make an honest attempt at each one, so 1% of overall grade is subtracted for each unexcused absence/non-submission/lack-of-fair-effort (*i. e.,* if the tutorial score is < 10/20 if that tutorial is not already counting).

Exams/Quizzes

There will be a Midterm exam for 10% of the grade and a Final Exam for 15% of the grade when scheduled by the registrar in the final examination period. Students may opt to produce a final project in place of the final exam.

Participation: in class and online via NotaBene (nb.mit.edu)

10% of the course grade is based on questions, comments, and answers supplied by you to the online readings on NotaBene. 5% will be based on satisfactory demonstration in class of how you produce the codes you hand in.

Evaluation and Grading

Class Element	Grade Percentage
Tutorials	60%
Midterm Exam	10%
Final Exam	15%
NotaBene Comments	10%
In-class code demonstration	5%

Important Policies and Resources

Academic Integrity

Every member of the University community is expected to maintain the highest standards of academic integrity. A student shall not submit work that is falsified or is not the result of the student's own effort. Infringement of academic integrity by a student subjects that student to serious penalties, which may include failure on the assignment, failure in the course, suspension from the University or other sanctions. Please consult Brandeis University Rights and Responsibilities for all policies and procedures related to academic integrity. A student who is in doubt regarding standards of academic integrity as they apply to a specific course or assignment should consult the faculty member responsible for that course or assignment before submitting the work. Allegations of alleged academic dishonesty will be forwarded to the Department of Student Rights and Community Standards. Citation and research assistance can be found at Brandeis Library Guides - Citing Sources.

For this course I am happy for you to discuss codes with each other, ask each other for help, even look at each other's codes and get help from Chat-GPT or other AI in order to learn how to do it or to understand a coding principle. I encourage such behavior when stuck. Moreover, you are allowed to download and alter some of the codes for the course available online at https://people.brandeis.edu/~pmiller/TEXTBOOK/index.html. I do require that you cite where you got help (cite the individual if they helped, or my website if based on a downloaded code, or Chat-GPT if that wrote some of the code). However, it is key that you *understand* what you produce and can explain what any line of code is doing and why. To ensure this, following week 3 of the course, I will ask each of you about the codes you are writing during discussions with 3-4 students per class.

Classroom Health and Safety

- Register for the Brandeis Emergency Notification System. Students who receive an emergency notification while attending class should notify their instructor immediately. In the case of a life-threatening emergency, call 911. As a precaution, review this active shooter information sheet.
- Brandeis provides this shuttle service for traveling across campus or to downtown Waltham, Cambridge and Boston.
- On the Brandeis campus, all students, faculty, staff and guests are required to observe the university's policies on physical distancing and mask-wearing to support the health and safety of all classroom participants. Face coverings must be worn by all students and instructors in classes with in-person meetings. Students and faculty must also maintain the appropriate 6 feet of physical distance from one another when entering, exiting, or being in the classroom and continue to sit in seats assigned by the professor to assist the university in its contract-tracing efforts. All faculty and students must also clean their work areas before and after each class session, using the sanitizing wipes provided by the University. (Classrooms will also be professionally cleaned by Brandeis custodial staff multiple times per day.) Review up to date COVID-related health and safety policies regularly.

Course Materials/Books/Apps/Equipment

Chapters of the book for the course, *An Introductory Course in Computational Neuroscience* by Paul Miller will be posted on Moodle and NotaBene. No purchase necessary. For advanced students who prefer more in-depth reading, the book *Theoretical Neuroscience* by Peter Dayan and Larry Abbott covers much of the same material. Background research papers cited in either textbook are available via the Brandeis Library.

Moodle

Moodle is the Brandeis learning management system. Login using your UNET ID and password. For Moodle help, contact Library@brandeis.edu.

Library

The Brandeis Library collections and staff offer resources and services to support Brandeis students, faculty and staff. Librarians and Specialists from Research & Instructional Services, Public Services, Archives & Special Collections, Sound & Image Media Studios, MakerLab, AutomationLab, and Digital Scholarship Lab are available to help you through consultations and workshops.

Privacy

To protect your privacy in any case where this course involves online student work outside of Brandeis password-protected spaces, you may choose to use a pseudonym/alias. You must share the pseudonym/alias with me and any teaching assistants as needed. Alternatively, with prior consultation, you may submit such work directly to me.

Student Support

Brandeis University is committed to supporting all our students so they can thrive. If a student, faculty, or staff member wants to learn more about support resources, the Support at Brandeis webpage offers a comprehensive list that includes these staff colleagues you can consult, along with other support resources:

- The Care Team
- Academic Services (undergraduate)
- Graduate Student Affairs
- Directors of Graduate Studies in each department, School of Arts & Sciences
- Program Administrators for the Heller School and International Business School
- University Ombuds
- Office of Equal Opportunity.