Fundamentals in computational neuroscience models (NSBV BC 2004)

Course number and term: NSBV2004BC, Fall 2023
Time and Location: MW 5:40pm-6:55pm, 327 Milbank Hall
Instructor information: Gabrielle J. Gutierrez, PhD, Assistant Professor at Barnard College
Office: Milbank 415-i, email: ggutierr@barnard.edu, office phone: 212-853-3840
Office hours: Tuesdays 2-4pm (or by appointment)
Computing Fellow: TBD

Prerequisites: NSBV BC1001 Introduction to Neuroscience, OR Introduction to Cellular and Molecular Biology (BIO BC 1502), OR permission of instructor.

Course description: Computational neuroscience is an exciting, constantly evolving subfield in neuroscience that brings together theories and ideas from many different areas in STEM such as physics, chemistry, math, computer science, and psychology. Through the exploration of computational models of neuronal and neural network activity, students will be introduced to a handful of quantitative STEM concepts that intersect with neuroscience. Before beginning this course students are expected to have learned about the action potential and synaptic transmission (see prerequisites). In this course, we will connect those neurobiological phenomena to quantitative STEM concepts and theories and then to computational models in Matlab.
This course is designed for students who want to take their first steps towards mathematical and computational models of the brain. Students interested in the computational track for the Neuroscience major should consider taking this course.

Course Objectives: Students will learn about and work with a few of the foundational computational neuroscience models relating to single neuron and neural network activity. Students will be exposed to the mathematical and scientific principles behind those models, and will develop the confidence to pursue a deeper exploration of those topics. Specifically, students will:

★ Learn about quantitative theories and concepts from other STEM disciplines (physics, chemistry, applied math, biology, computer science, psychology, etc) through the lens of the action potential and synaptic transmission.
★ Implement computational neuroscience models of neurons and neural networks using Matlab.
★ Identify the scope of a neuroscience model and determine what it can and cannot tell us.
★ Compare models and select an appropriate model for a given scientific question from among the models covered in this course.

Grading:

Assessment type	**Percent of final grade**
Exam 1	25%
Problem sets	25%
Project (build your own conductance-based neuron model)	25%
Final Exam	25%

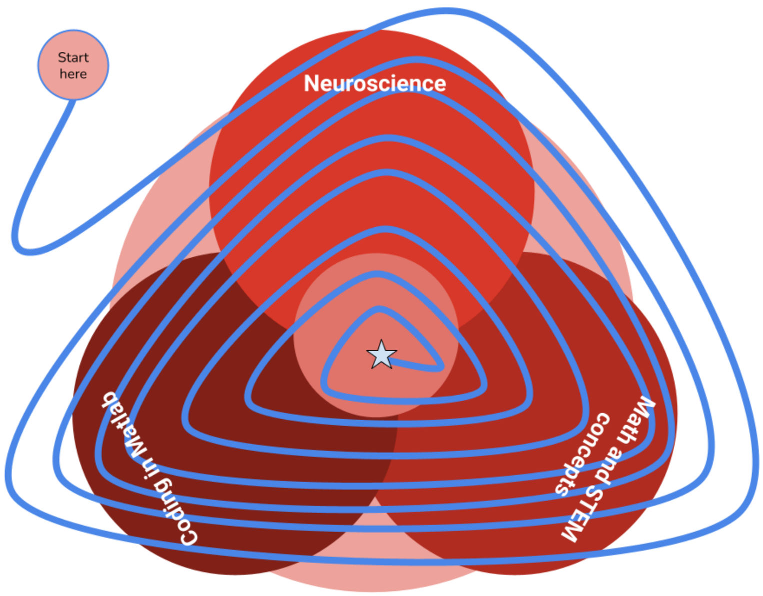
The first **Exam** will test students' understanding of the material in the background module. It will be an in-class exam that will consist of multiple choice and short answer questions. Exam 1 will be on (date TBD).

Weekly **HWs and/or problem sets** will be available at the beginning of the week of the material they cover and they will be due by Sunday at midnight.

Students will complete a **Project** after the second module. Each student will create their own conductance-based neuron model in Matlab. The project is due on (date TBD).

The **Final Exam** will have a similar format to the first exam but it will test the core concepts outlined in the learning objectives as well as the topics from all of the modules with an emphasis on the Neuron models and the Neuronal synapses and circuit models modules. The final exam is projected to take place on (TBD).

Course Organization: (graphic syllabus)



Modules:

Module 1 - background concepts

Module 2 - neuron models

Module 3 - neuronal circuit models

Textbook and course materials:

An Introductory course in Computational Neuroscience (MIT Press)

Author: Paul Miller

ISBN: 9780262038256

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Hardcover: $50, rent e-book: $25

https://clio.columbia.edu/catalog/13870416

Additional Matlab tutorials, practice materials, and assignments provided by professor (website links and digital LiveScript notebooks)

Schedule by week:

Week	topic	description	Readings in preparation	Accompanying HW
0	Course overview	Birds-eye view of comp neuro models and the subset we will explore in this course.	read syllabus and optional reading (https://www.brainfacts.org/in-the-lab/tools-and-techniques/2018/to-understand-the-brain-you-have-to-do-the-math-021318)	
1	Neuroscience review	review action potential and synaptic transmission	textbook sections 1.1, 1.2, Membrane potential | Khan Academy, Neuron action potentials | Khan Academy, Action Potential in the N...	Problem set #1
	Pocket calculus I	introduce differential equations and what they show us.	Textbook section 1.4.1 through Example 1	Problem set #1
2	Pocket calculus II	tricks for how to "dissect" any equation.	Rest of Textbook section 1.4.1 (skip proof) pgs. 16-21. Strogatz NYT article (optional). Make a MathWorks account.	Problem set #2
	Matlab basics I	Tutorial work sessions covering some coding principles	textbook section 1.4.2, Matlab Onramp tutorial up to section 5	Problem set #2

			https://matlabacademy.mathworks.com/details/matlab-onramp/gettingstarted	
3	Matlab basics II	Tutorial work sessions covering some coding principles - for loops	textbook section 1.5 (up to 1.5.8), Matlab Onramp tutorial up to section 11	Problem set #3 and Finish Matlab tutorial
	Pocket calculus with Matlab		textbook rest of section 1.5 starting from 1.5.8 onwards, and textbook section 1.6 (up to 1.6.6)	Problem set #3
4	E&M principles of closed circuits	Intro to Ohm's law and electrical circuit theory	textbook section 1.3, 2.1-2.2	Mini Problem set #4
	Leaky integrate-and-fire neuron	Concepts behind basic model of spiking neuron	textbook section 2.3	Problem set #5
5	Exam day			
	Leaky integrate-and-fire neuron (continued)	Coding a basic model of spiking neuron	textbook section 2.3.2, 2.5.1, 2.5.2, and peruse section 2.4 (tutorial 2.1)	Problem set #5
6	Hodgkin-Huxley model I	Introduction to neuroscientific discoveries that led to HH model	J phys paper and theory of AP paper	Problem set #6

	Hodgkin-Huxley model II	Exploring the dynamics of the steady state HH equations with and without code	textbook section 4.1, 4.2 up to 4.2.3, Example 5 (pg. 22)	Problem set #6
7	Hodgkin-Huxley model III	Gating variables	Genesis ch. 4 (up to section 4.5)	Problem set #7
	Hodgkin-Huxley model IV	Another day of working with HH model code. This time we add in the gating variables.	textbook section 4.2.3, 4.4, and 4.5 HH model review paper (optional)	Problem set #7
8	working with functions in Matlab	Basics about functions	Matlab tutorial on functions (https://matlabacademy.mathworks.com/details/matlab-fundamentals/mlbe#module=15), textbook section 1.5.10	
	Model selection and dynamical systems	How does one choose the best model for their scientific question?	textbook section 7.1-7.3.0, Matlab tutorial on Troubleshooting (https://matlabacademy.mathworks.com/details/matlab-fundamentals/mlbe#module=16)	
9	Election holiday/project due date			Project: invent your own conductance-based model neuron with conductances of your

				own choosing.
	Synaptic connections	Review of synaptic connectivity types	textbook section 5.1-5.2	Problem set #8
10	Modeling synapses	Overview of dynamical synapses	Textbook section 5.3	Problem set #8
	Neural network connectivity and the connectivity matrix	Introduction to general Neural networks and connectivity matrices	~~Textbook section 5.5 (review 1.4.2)~~ Gap junctions primer (optional)	Problem set #8
11	Neural circuits I	Lecture about STG circuit	textbook section 5.7-5.8 (up to 5.8.3)	Problem set #9
	Thanksgiving holiday			
12	Neural circuits II	Model selection. I'll introduce several new models that could be used to model an STG neuron.	"Central pattern generators and the control of rhythmic movements" article	Problem set #9
	Neural circuits III	Phase response curves	textbook section 5.8.3	Problem set #9
13	Hebbian plasticity and learning	Lecture about how a psychology theory informed a neurobiological model.	Textbook sections 8.1 (up to 8.1.1), 6.1, 6.2 (up to 6.2.1)	Problem set #10
	Pattern completion	Lecture about machine learning origins	Textbook section 8.1.1 (peruse 8.2)	Problem set #10

14	Final review			

My advice to students:

- The readings are short but dense, so take the time to make notes while reading and maybe even give the material a second read.
- Write down your questions after doing the readings and bring them to class.
- Start working on the problem sets as soon as the material is covered in class while the concepts are still fresh. Review and revise your answers before turning them in.
- Make use of office hours - I'm here to help.

Late assignments policy:
Late assignments will incur a 10% penalty for each day it is late. This penalty does not apply to excused late submissions.

Barnard Policies:

Honor Code

Approved by the student body in 1912 and updated in 2016, the Code states:

We, the students of Barnard College, resolve to uphold the honor of the College by engaging with integrity in all of our academic pursuits. We affirm that academic integrity is the honorable creation and presentation of our own work. We acknowledge that it is our responsibility to seek clarification of proper forms of collaboration and use of academic resources in all assignments or exams. We consider academic integrity to include the proper use and care for all print, electronic, or other academic resources. We will respect the rights of others to engage in pursuit of learning in order to uphold our commitment to honor. We pledge to do all that is in our power to create a spirit of honesty and honor for its own sake.

The Barnard Honor Code includes relevant language for the proper use of electronic class material.

"*We consider academic integrity to include the proper use and care for all print, electronic, or other academic resources..* "

To be clear, this means that recorded class content — from lectures, labs, seminars, office hours and discussion groups — is the intellectual property of your professor and your fellow students, and should not be distributed or shared outside of class.

Center for Accessibility Resources & Disability Services (CARDS)

If you believe you may encounter barriers to the academic environment due to a documented disability or emerging health challenges, please feel free to contact me and/or the Center for Accessibility Resources & Disability Services (CARDS). Any student with approved academic accommodations is encouraged to contact me during office hours or via email. If you have questions regarding registering a disability or receiving accommodations for the semester, please contact CARDS at (212) 854-4634, cards@barnard.edu, or learn more at barnard.edu/disabilityservices. CARDS is located in 101 Altschul Hall.

Affordable access to course texts and materials

All students deserve to be able to study and make use of course texts and materials regardless of cost. Barnard librarians have partnered with students, faculty, and staff to find ways to increase student access to textbooks. By the first day of advance registration for each term, faculty will have provided information about required texts for each course on CourseWorks (including ISBN or author, title, publisher, copyright date, and price), which can be viewed by students. A number of cost-free or low-cost methods for accessing some types of courses texts are detailed on the Barnard Library Textbook Affordability guide (library.barnard.edu/textbook-affordability). Undergraduate students who identify as first-generation and/or low-income students may check out items from the FLIP lending libraries in the Barnard Library (library.barnard.edu/flip) and in Butler Library for an entire semester. Students may also consult with their professors, the Dean of Studies, and the Financial Aid Office about additional affordable alternatives for having access to course texts. Visit the guide and talk to your professors and your librarian for more details.

Health and Wellness

Furman Counseling Center

The Rosemary Furman Counseling Center offers health and wellness resources even when you are not on campus. Appointments with a counselor can be scheduled on their website: https://barnard.edu/rosemary-furman-counseling-center. They are also holding listening sessions related to changes to the Fall 2020 semester (these sessions do not have a therapeutic focus). They also list several emergency services that you can use.

General Resources

It is important for undergraduates to recognize and identify the different pressures, burdens, and stressors you may be facing, whether personal, emotional, physical, financial, mental, or academic. We as a community urge you to make yourself--your own health, sanity, and wellness--your priority throughout this term and your career here. Sleep, exercise, and eating well can all be a part of a healthy regimen to cope with stress. Resources exist to support you in several sectors of your life, and we encourage you to make use of them. Should you have any questions about navigating these resources, please visit these sites:

- http://barnard.edu/primarycare
- http://barnard.edu/counseling
- http://barnard.edu/wellwoman/about
- Stressbusters Support Network

Class attendance policy

Students are expected to attend all classes. There will be no makeups for missed in-class quizzes. A missed quiz is a zero. At the end of semester, the lowest 2 quiz scores will be dropped for each student. In the case of prolonged, and/or excused absence, see instructor.

Class laptop policy

Students are permitted to use laptops in class to take notes and to engage with the course material. Students may not engage in other activities on their laptops while in class.