NSC 3270 / 6270 Computational Neuroscience
Tues / Thurs 9:30–10:45am
Furman Hall Room 311

Instructor

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Course Overview

Computational neuroscience is an approach to understanding the information content of neural signals by modeling the nervous system at many different structural scales, including the biophysical, the circuit, and the systems levels.
- T. Sejnowski and T. Poggio

Computational neuroscience is the study of brain function in terms of the information processing properties of the structures that make up the nervous system. It is an interdisciplinary science that links the diverse fields of neuroscience, cognitive science, and psychology with electrical engineering, computer science, mathematics, and physics.
- Wikipedia

In this course, we will use computational techniques to understand how the brain works. The first two-thirds of the course will be on developing models of the brain, computer simulations called neural network models. The remaining third of the course will be on computational techniques for analyzing and understanding neural data.

You can understand the brain at a variety of spatial and temporal scales, from molecular and cellular processes within a single neuron, to the detailed operations of a single neuron or small assemblies of neurons, to larger-scale neural networks that give rise to behavior. Our focus will be on the latter, with a particular emphasis on developing neural network models and methods of analysis in domains such as perception, memory, and decision making.

This is a neuroscience course, and our focus will be on neural network models as models of the brain and computational methods for analyzing brain data. That said, many of the techniques we will discuss and use are widely applicable. The neural network models originally developed by psychologists, neuroscientists, and cognitive scientists as models of the brain are now key engines for modern artificial intelligence, machine learning, and data science. And the computational analysis techniques used to understand brain data can be applied to many kinds of data. I will try to make these broader connections when appropriate – but my focus will be on teaching this course as a neuroscience course, not as a data science course or as a computer science course.

We will rely heavily on demonstrations and hands on experience – in the form of homework assignments – developing, testing, and evaluating computational models and computational approaches.

Prerequisites / Background Knowledge

Computer Programming: A good working knowledge of computer programming in a high-level language (e.g., Matlab, Python, R, C/C++, Java) is required. We will be using Python in this course. Python was chosen because of the availability of tools (Keras and Tensorflow) for simulating neural network models and for the tools available for analyzing neural data, as well as for its prevalence as a programming language used for simulations and analyses in neuroscience. For undergraduates enrolled in NSC 3270, at least one semester of computer programming at Vanderbilt (or equivalent) is required, not necessarily in Python. For graduate students enrolled in NSC 6270, prior coursework or other experience using a computer programming language, not necessarily Python, will be assumed. If you do not know how to program at all in any modern programming language (e.g., Matlab, Python, R, C/C++, Java), this course is not for you. All of the homework assignments will involve computer programming, and nearly all of the points used to compute the final course grade will be based on those assignments.

I understand that not everyone will know Python. I will cover a few of the essential elements of Python early in the semester, and will include extensive sample Python code throughout the semester, but students without any knowledge of Python may need to supplement with readings and/or videos on their own, some of which will posted on Brightspace. Students will also be able to post specific questions about Python coding on Piazza (as described later).

Neuroscience: For both undergraduates and graduate students, I will assume what should be a level of neuroscience covered in an advanced high school biology course or an introductory college-level biology, psychology, or neuroscience course. Students with no knowledge of neuroscience should be able to supplement by searching for terms and concepts online.

Calculus: Because most computational models and computational approaches are described in the language of mathematics, I will assume that students have a basic understanding of calculus, especially the fundamental concepts of the derivative and the integral. For undergraduates, at least one semester of calculus is required. For graduate students without this prerequisite knowledge of elementary calculus, gaps will need to be filled with outside readings and/or videos.

Vector/Matrix Algebra: A basic knowledge of vectors and matrices, and operations on vectors and matrices will be assumed, although I will review some concepts and post Python code related to the kinds of vector/matrix operations we will use in the course.

Laptops

Students are encouraged to bring laptops to class. I may distribute example code before class that will be used during class. I must insist that everyone please refrain from using their laptops for any non-class purposes during class, as it can be very distracting to others sitting nearby.

Course Requirements and Grading

Homework assignments will be handed out regularly – roughly weekly – throughout the course to allow students the opportunity to put the ideas discussed during class into practice. Homework assignments are the primary determinant of the course grade. There will be no graded quizzes or exams. There is no final exam.

This is an in-person class, and as such there is an expectation that you will attend class in person. Poor attendance and participation can be used to lower the final grade, and may be used to adjudicate borderline grades.

Final letter grades will be based on percentages as follows:

		A	92.5 – 100%	A-	90.0 – 92.5%
B+	87.5 – 90.0%	B	82.5 – 87.5%	B-	80.0 – 82.5%
C+	77.5 – 80.0%	C	72.5 – 77.5%	C-	70.0 – 72.5%
D+	67.5 – 70.0%	D	62.5 – 67.5%	D-	60.0 – 62.5%
		F	0.0 – 60.0%		

While I encourage students to help each other out with conceptual misunderstandings, all homework assignments must be completed individually. Unexcused late assignments will be penalized 10% for every 24 hours late, starting from the time class ends, for a maximum of two days, after which they will earn a 0.

Any student auditing the course is expected to attend class and can participate in a way commensurate with the amount of work they do on class homework assignments.

You will turn in homework assignments using Brightspace. I ask a couple of things: First, unless you are submitting just a single file (.ipynb or .py) for your assignment, please submit a single (compressed) ZIP file rather than multiple files. Second, please make sure that you submit everything that's needed for the program in order to run your code successfully, which includes not only files you created but copies of any files I might have given you as part of the assignment (unless stated otherwise).

Additional Graduate Student Requirement

Graduate students are required to enroll in NSC 6270. In addition to completing the homework assignments and attending class, graduate students are required to complete a small final project in Python that relates somehow to the principles and approaches discussed in the course. Graduate students will meet with the professor to discuss potential projects and get approval to proceed. The final submitted project will consist of Python code that can be run and a short (one or two page) description of what the code is used for. The final project can be closely related to your graduate research but it does not need to be. The final project will constitute 10% of your final course grade.

Brightspace

All course materials (readings, web links, lecture slides, homework assignments, example code) will be posted on the Brightspace site for this course. You will also turn in your homework assignments on Brightspace. While you can turn in a homework assignment more than once, we will only look at and grade the last version you submit. You can also view your grades and comments for the assignments within Brightspace.

Piazza

We will use Piazza to facilitate questions (and answers) about Python and Tensorflow installation and setup, Python coding, Jupyter notebooks, IDE use and debugging, and assignments. Rather than emailing questions to the myself or the TA, I encourage you to post questions on Piazza. Answers we give on Piazza might help other students with similar questions. I also encourage students to help other students on Piazza – doing so can help you learn the material more deeply. Regular activity on Piazza (asking and answering questions) may be used to adjudicate borderline grades.

The course site on Piazza is here: https://piazza.com/vanderbilt/fall2022/nsc32706270

Readings

There is no book for this course. Instead, course readings (book chapters, articles, links to videos and web sites) will be posted on Brightspace and will be announced in class.

Python

The Python programming language will be used for all assignments in this course.

Python is a high-level computer programming language particularly well suited to computational neuroscience applications. It is free, open software that runs on multiple platforms (Windows, Mac, and Linux). It is highly extensible with thousands of libraries and modules written and shared by scientists and engineers from around the world.

Details on setting up Python for this course will be posted on Brightspace.

Code of conduct

We are committed to diversity, equity, and inclusion, and we strive to create a welcoming learning environment.

All forms of harassment are prohibited. Specific prohibited behaviors include but are not limited to the following: Harassment or intimidation based on gender, gender identity, gender expression, age, sexual orientation, disability, appearance, body size, race, ethnicity, political orientation and views, religion (or lack thereof), or other group status; unwelcome behavior as well as verbal or written comments related to the above categories that create a hostile environment (e.g., sexist or racist jokes); sexual harassment or intimidation, including unwelcome sexual attention; harassing photography or recording; stalking or following (physical or virtual); advocating for, or encouraging, any of the above behavior.

Individuals asked to stop any harassing behavior are expected to comply immediately. The professor retains the right to take any actions to keep the course a welcoming educational environment. These actions include simply warning the offender, expulsion from online synchronous activities, and lowering of one's course grade.

If you are being harassed, notice that someone else is being harassed, or have any other concerns, please report it to Prof. Polyn immediately. We will make every effort to ensure that you feel safe and welcome in this class.

(Some of the language in this section was modified from the code of conduct of the Society for Mathematical Psychology)

Tentative Course Topics

The complete schedule of topics will be outlined and updated regularly on Brightspace. Here is a tentative list of possible topics and approaches we may discuss over the course of the semester:

Introduction to Computational Neuroscience
Introduction to Matlab
Simple Feedforward Networks
Perceptrons
Multi-Layered Neural Networks
Supervised Network Learning
Unsupervised Network Learning
Hopfield Networks
Recurrent Neural Networks
Reinforcement Learning
Integrate and Fire Networks
Spiking Neural Networks
Deep Learning and Convolutional Neural Networks
Neural Models of Visual Perception
Neural Models of Memory
Neural Models of Decision Making
Scalp Electroencephalography (EEG) Analyses
Intracranial Electrocorticography (ECoG) Analyses
Analyzing Neural Oscillations
Functional Magnetic Resonance Imaging Analyses
Multivariate Pattern Analysis Techniques
Representational Similarity Analysis
Model-based Cognitive Neuroscience

Vanderbilt's Honor Code Governs All Work in this Course