Instructor: Prof. Zack Kilpatrick, ECOT 647, zpkilpat@colorado.edu

Lecture Time & Location: MWF 11-11:50am, CASE E340

Office hours: Mon 12-1:30pm, Tues 12-1pm, or by appt

Course webpage: https://zpkilpat.github.io/appm4370.html

Course Overview: Applies mathematical and computational methods to in neuroscience. Techniques from linear algebra, differential equations, introductory dynamical systems, probability, statistics, stochastic processes, and machine learning will be learned and used. Topics in neuroscience include neural spiking, network dynamics, probabilistic inference, learning, and plasticity. You will learn how the brain uses computational principles to enact decision making, vision, and memory. Required background includes linear algebra, differential equations, and programming. Probability recommended. Students will hone programming skills in MATLAB/Python.

This course is for mature undergraduates (4000 level) and graduate students (5000 level). We will move quickly: students will be expected to supplement lectures with reading and problem sets will be extensive. This intensive learning experience will provide students with a working knowledge of a wide repertoire of methods and concepts in computational neuroscience, and should result in the ability to pick up and parse current publications in the field.

***Tentative* and *Ambitious* Course Outline:**

Week	Material Covered
1	Electrical properties of neurons; integrate-and-fire models; Hodgkin-Huxley
2	Simulating ODEs; synapses; short-term plasticity; release probability
3	Linearization; phase-planes; eigenvalue problems
4	Nonlinear spiking models; adaptation
5	Noise-driven spiking; Poisson spiking; escape rates; Fokker-Planck equation
6	Population codes; maximum likelihood; Intro to rate models;
7	Competitive neural networks; decision-making; drift-diffusion models
8	Continuum models; bump attractors; traveling waves
9	Long-term plasticity; Hebbian learning; principal components analysis
10	Correlation analysis; dimension-reduction; generalized linear models
11	Readouts; perceptrons; backprop; convolutional networks
12	Recurrent networks; chaotic networks; learning in recurrent networks
13-15	Project work time

Enforced Prerequisites: Differential Equations (APPM 2360 or equivalent) and Matrix Methods (APPM 3310 or equivalent) with a minimum grade of C-.

Recommended Prerequisite: APPM 3570/STAT 3100 (Applied Probability); STAT 2600 (Intro to Data Science); CSCI 3022 (Intro to Data Science with Probability and Statistics); or equivalent.

Primary Text: *Neuronal dynamics: From single neurons to networks and models of cognition* by Wulfram Gerstner, Werner M. Kistler, Richard Naud, & Liam Paninski; Cambridge University Press (2014)
Online: https://neuronaldynamics.epfl.ch/online/index.html (softcover also in bookstore)
Supplementary Videos: https://lcnwww.epfl.ch/gerstner/NeuronalDynamics-MOOCall.html

Additional Recommended Texts:
Theoretical neuroscience by Peter Dayan & Larry F. Abbott; MIT Press (2005)
Spikes, decisions, and actions: Dynamical foundations of neuroscience by Hugh R. Wilson; Oxford Uni-

versity Press (1999). Online: http://cvr.yorku.ca/webpages/spikes.pdf (introductory)
A short course in mathematical neuroscience by Philip Eckhoff & Philip Holmes
Online: https://www.ictp-saifr.org/wp-content/uploads/2015/05/MathNsci.pdf

Online python resources: I will provide quite a bit of example code and jupyter notebooks at the course github repo: https://github.com/zpkilpat/appm4370compneuro
There are plenty of other online python tutorials/references you can consult. Here are a few:
https://www.learnpython.org/
http://cs231n.github.io/python-numpy-tutorial/
https://docs.scipy.org/doc/numpy/user/numpy-for-matlab-users.html
https://neuronaldynamics-exercises.readthedocs.io/en/latest/ (companion exercises to textbook)

Grading: 60% for six problem sets; 20% for 'no collaboration' problems; 20% for final project. Final grades determined on a 10-point scale, subject to possible *down*shifting.

Problem sets: Six problem sets due (roughly) biweekly will be assigned. You may these discuss problems with other students or with me, but write up your own work legibly and clearly. You must comprehend the material and be able to solve the problems on your own. Problem sets are graded on a 0-100 scale. Your time and my time are valuable. **Therefore, if I cannot understand your results (e.g. poorly written calculations; incomprehensible code outputs), then you will get the problem wrong.** ***Problem sets are due by 11am (in class) on the due date; please get your set to me beforehand if you cannot make it to class.*** Late homework will not be accepted.

'No collaboration' problems: Four 'no collaboration' problems will be given to test your grasp of material you practice on problem sets. These are meant to function as take home exams, and should take a well prepared student about an hour to complete, but you may take as much time as you like to work on them prior to the due date. You may use course books, notes, or homework, **but you may not consult with others or with the internet.** You will sign an honor pledge to indicate you have complied with these conditions. Late problems will not be accepted.

Assignment/Exam Schedule	**Date Assigned**	**Due Date**
Problem set 1	Mon, Jan 13	Fri, Jan 24
Problem set 2	Fri, Jan 24	Wed, Feb 5
No collaboration problem 1	Wed, Feb 5	Mon, Feb 10
Problem set 3	Wed, Feb 5	Wed, Feb 19
No collaboration problem 2	Wed, Feb 19	Mon, Feb 24
Problem set 4	Mon, Feb 24	Wed, Mar 4
No collaboration problem 3	Wed, Mar 4	Mon, Mar 9
Problem set 5	Wed, Mar 4	Wed, Mar 18
No collaboration problem 4	Wed, Mar 18	Mon, Mar 23
Problem set 6	Wed, Mar 18	Wed, Apr 8
Develop project proposal	Mon, Feb 24	Fri, Mar 20
Final project report & talk	Fri, Mar 20	Fri, Apr 24

Projects: There is a vast array of ongoing research problems in computational neuroscience. I can only skim the surface as part of the lectures and assigned problems sets in this course. Projects give you the opportunity to delve deeper into a topic of interest to you.

By Mon, Feb 24, I will post a list of possible project topics, chosen to exhibit a range of applications in computational neuroscience. You may also develop a project proposal outside of this list

if you like – please come and talk to me about this well before the proposal deadline if you do. Undergraduates must work in pairs, graduate students may work in pairs or alone. Part of *your* responsibility in working as a pair is to make sure both of you does their fair share. Please email me ASAP informing me of the project you've chosen and the members of your project group.

By 11am on Friday, March 20, you must send to me a one page proposal detailing the scientific question you will answer in your project, the mathematical methods and numerical experiments you will use to try and answer this question, what references you will use, some preliminary ideas about what you think you will find, and your plan for addressing any pitfalls you run into during the question answering process. Each pair only needs to submit one proposal.

By 11am on Fri, Apr 22, each pair/individual must submit a written report. All students must also submit to me an account of all they did for the project, as well as a peer evaluation if they worked with a partner. After this, each individual/pair will give a 15 minute talk on their project, scheduled in class (Fri Apr 24, Mon Apr 27, Wed Apr 29) and the final exam period (Sun May 3 from 7:30-10pm).

Projects will be graded based on the report and oral presentation. You will be expected to demonstrate understanding of the reference material, show significant progress in answering your posed research question, and display an easy-to-read presentation in your report and talk complete with plots/visuals. Expectations for those taking the 5000 level course are higher.

Class Policies:

- Classroom discussion and questions are encouraged and supported.
- I will make arrangements for classes I miss due to travel or illness.
- Arrive on time (5 minutes early if possible) as warm-up problems and important announcements are presented at the beginning of class.
- Late homework/exams/projects are not accepted.
- Violations of the honor code will be handled according to university policy (see below)

Students with disabilities (official CU policy): If you qualify for accommodations because of a disability, please submit your accommodation letter from Disability Services to me in a timely manner so that your needs can be addressed. Disability Services determines accommodations based on documented disabilities in the academic environment. Information on requesting accommodations is located on the Disability Services website.

Contact Disability Services at 303-492-8671 or dsinfo@colorado.edu for further assistance. If you have a temporary medical condition or injury, see Temporary Medical Conditions under the Students tab on the Disability Services website.

Classroom Environment: Students and faculty each have responsibility for maintaining an appropriate learning environment. Those who fail to adhere to such behavioral standards may be subject to discipline. Professional courtesy and sensitivity are especially important with respect to individuals and topics dealing with race, color, national origin, sex, pregnancy, age, disability, creed, religion, sexual orientation, gender identity, gender expression, veteran status, political affiliation or political philosophy. Class rosters are provided to the instructor with the student's legal name. I will gladly honor your request to address you by an alternate name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. For more information, see the policies on classroom behavior and the Student Code of Conduct.

Honor Code: All students enrolled in a University of Colorado Boulder course are responsible for knowing and adhering to the Honor Code. Violations of the policy may include: plagiarism, cheating, fabrication, lying, bribery, threat, unauthorized access to academic materials, clicker fraud, submitting the same or similar work in more than one course without permission from all course instructors involved, and aiding academic dishonesty. All incidents of academic misconduct will be reported to the Honor Code (honor@colorado.edu); 303-492-5550). Students who are found responsible for violating the academic integrity policy will be subject to nonacademic sanctions from the Honor Code as well as academic sanctions from the faculty member. Additional information regarding the Honor Code academic integrity policy can be found at the Honor Code Office website.

Sexual Misconduct, Harassment, Discrimination, and/or Related Retaliation: The University of Colorado Boulder (CU Boulder) is committed to fostering a positive and welcoming learning, working, and living environment. CU Boulder will not tolerate acts of sexual misconduct intimate partner abuse (including dating or domestic violence), stalking, protected-class discrimination or harassment by members of our community. Individuals who believe they have been subject to misconduct or retaliatory actions for reporting a concern should contact the Office of Institutional Equity and Compliance (OIEC) at 303-492-2127 or cureport@colorado.edu. Information about the OIEC, university policies, anonymous reporting, and the campus resources can be found on the OIEC website.

Please know that faculty and instructors have a responsibility to inform OIEC when made aware of incidents of sexual misconduct, discrimination, harassment and/or related retaliation, to ensure that individuals impacted receive information about options for reporting and support resources.

Religious Observances: Campus policy regarding religious observances requires that faculty make every effort to deal reasonably and fairly with all students who, because of religious obligations, have conflicts with scheduled exams, assignments, or required attendance. If you have any such obligations on assignment due dates or exam days, let me know by the end of the first week of class, and we can work together to accommodate your schedule.

See the campus policy regarding religious observances for full details.

Preferred Student Names and Pronouns: I will gladly honor your request to address you by an alternate/preferred name or gender pronoun. Please advise me of this preference early in the semester so that I may make appropriate changes to my records. Also, you can update your preferred names and pronouns via the student portal; that preferred name and/or pronoun will then be listed on my roster. Please note that in the absence of such information, the name that appears on my roster will be the one I check and refer to in my gradebook.