Mathematical Tools for Neuroscience (NEU 314)
Fall Semester, 2016

Time: Tues/Thurs 10:00-10:50am.
Location: PNI A02.

Instructor: Jonathan Pillow (pillow at princeton).
Office hours: Thurs 11a-12p. (PNI 254).

AIs: Alex Riordan (riordan.alexander at gmail). OH: Tu 11a-12p (PNI A-level study hall)
Nick Roy (nroy at princeton). OH: Weds 8-9p (PNI A-level study hall)
Anqi Wu (anqiw at princeton). OH: Fri 1-2p (PNI 232C)

Lab sections: 1. Tues 7:30-10:20p [AI: Nick].
2. Weds 1:30-4:20p [AI: Anqi].
3. Thurs 7:30-10:20p [AI: Alex].

Description: This course aims to provide a comprehensive introduction to the mathematical and computational tools needed for analyzing neural systems and neural data. The course will introduce students to topics in linear algebra, differential equations, and probability & statistics, with a heavy emphasis on applications to neurobiology. Coursework will focus primarily on problem sets requiring the implementation of various analyses and models in Python. The course will seek to give students both a good intuitive understanding and a practical mastery of various mathematical and computational methods, and equip them with programming and data visualization skills that are increasingly important to scientific inquiry in general, and neuroscience in particular.

Topics include:

I. **Linear Algebra & Least Squares** (5 weeks) Vectors and matrices, orthogonality, linear projection, span, basis, vector spaces, singular value decomposition, least-squares regression, principal components analysis, linear discriminants.

II. **Probability & Statistics** (5 weeks) Basic probability, estimation, Bayes' theorem, bias/ variance, optimization, bootstrapping, cross-validation, Poisson process, generalized linear models, information theory, Bayesian inference.

III. **Dynamics and Dynamical Systems** (3 weeks). Ordinary linear differential equations, fixed points, limit cycles, stability analysis.

FORMAL STUFF

Prerequisites: Good working knowledge of calculus and high school math topics (e.g., a friendly relationship with log, exp, cos, sin, etc.). Some programming experience is helpful but not required. Python programming will be introduced in the early lab sessions.

Format: The course consists of two 1-hour lectures per week, and a 3-hour computer lab problem session per week. The course includes a sequence of homework assignments primarily in the form of computer programming exercises. These are essential for learning the material. A short quiz on material from the previous week will be given at the beginning of class on Thursdays.

Requirements: Take-home problem sets, approximately 1 per week, and in-class quizzes. There is no final exam.

Grading: Grades will be based on the following breakdown:
Homework: 75%
Quizzes: 20%
Participation: 5%

Homework: Homework problem sets will involve a mix of programming assignments and paper-and-pencil math problems (with substantially more of the former). The goal of these assignments is to force students to put the mathematical concepts from class into practice. I believe that writing a computer program to implement or test a mathematical concept provides a much deeper form of understanding than merely writing down an analytical derivation. Many of the functions you write will also serve as prototypes for data analysis problems you will face in real neuroscience research.

All homeworks will be submitted in the form a Jupyter notebook. (Students will use LaTeX markup within the notebook to answer to analytical / paper-and-pencil math problems). Each homework assignment will count equally, so the homework grade will be the average over all assignments.

Quizzes: Every Thursday class will begin with a 5-minute quiz about material from the previous week. These quizzes should be easy for students who successfully completed and understood the homework from the previous week. The goal of these quizzes is to make sure students have genuine understanding of the homework solutions and how they work, without assistance from AIs or fellow students.

Each student can drop their three lowest quiz scores. Makeups will not be given; students who need to miss a class can simply count any missed quizzes among their lowest three.

Labs: There are three weekly lab sessions. The primary focus of lab sessions will be to work on problem sets. The AI will begin each session with a brief overview and field any questions about lecture material. There will often be warm-up problems, but otherwise you are free to work on homework problem sets, individually or in collaboration with other students. There will be no writeup or additional assignments associated with labs, but attendance is mandatory: this is your chance to get to know fellow students and to get 1-on-1 help from the AI. There are shared computers in the lab, but it is recommended to bring your own laptop.

Participation: Participation in class, lab sessions, and online on Piazza is strongly encouraged. Your questions and answers will help you and your fellow students learn more.

Attendance: Attendance will be taken at lab sessions, and count towards the 5% participation grade.

Text: There is no textbook. Lecture notes and supplementary reading materials will be posted on the course website and Piazza.

Collaboration and Academic Integrity: You are welcome to work together on problem sets (I would even encourage it), but the work you submit should be uniquely your own, prepared by your own hand. Students should understand every step in their code such that they could implement it again from scratch without help from anyone.

RESOURCES

Piazza: We encourage all students to post questions to Piazza instead of sending email. This will allow others to benefit from your question, and will often result in a faster and more complete answer (since your fellow students may post answers before any of the instructors can). Please participate on Piazza, and endorse questions and answers as you see fit. Piazza activity will count toward the 5% participation grade!

Course Piazza page: piazza.com/princeton/fall2016/neu314/home
Piazza course signup link: piazza.com/princeton/fall2016/neu314

Course website: http://pillowlab.princeton.edu/teaching/mathtools16fall/
I'll also maintain a course website where I'll post lecture notes and supplementary reading materials. (I will also post everything on Piazza, so I don't expect there to be much need for this.)

Python: All homework assignments will require programming solutions in Python. Learning to use Python will be a primary goal of early lab sessions. To install Python, we recommend installing the Anaconda development environment, which contains Python and a collection of important / popular packages. We will be using Python 3 (not Python 2), so when you install Anaconda, choose that one (currently Python 3.5). Installing Anaconda will also Jupyter (interactive notebooks) and Spyder (a development environment).

Computing Support: The OIT Help Desk is open 24 hours a day, seven days a week, to help you with your computing questions. You can reach the Help Desk at http://www.princeton.edu/helpdesk, via phone at 609-258-HELP(4357), e-mail at helpdesk@princeton.edu, or chat from the OIT home page http://www.princeton.edu/oit .