Electrical & Computer ENGINEERING

Carnegie Mellon University Course Syllabus

18-698 / 42-632: Neural Signal Processing
Spring 2023

Course Personnel:

Instructor:

Byron Yu
Office: B204 Hamerschlag Hall
Email: byronyu@cmu.edu

Teaching Assistants:

Megan McDonnell
Email: mmcdonnell@cmu.edu

Sravan Venigalla
Email: svenigal@andrew.cmu.edu

Mingxi (Marshall) Chen
Email: mingxic@andrew.cmu.edu

Course Description:
The brain is among the most complex systems ever studied. Underlying the brain's ability to process sensory information and drive motor actions is a network of roughly 10^11 neurons, each making 10^3 connections with other neurons. Modern statistical and machine learning tools are needed to interpret the plethora of neural data being collected, both for (1) furthering our understanding of how the brain works, and (2) designing biomedical devices that interface with the brain. This course will cover a range of statistical methods and their application to neural data analysis. The statistical topics include latent variable models, dynamical systems, point processes, dimensionality reduction, Bayesian inference, and spectral analysis. The neuroscience applications include neural decoding, firing rate estimation, neural system characterization, sensorimotor control, spike sorting, and field potential analysis.

Course goals:
There are two primary goals for the course: (1) to introduce the statistical tools used to study large-scale neural activity, and (2) to bring out the real-world challenges of working with experimental data. By the end of the course, students should be able to ask research-level questions in neural signal processing, as well as develop new statistical tools for problems in their own research. In short, this course serves as a stepping stone to research in neural signal processing.

Number of Units: 12

Pre-requisites:
This course is ideally suited for students with a solid background in basic probability and linear algebra. Prior knowledge of neuroscience is welcome, but not required. Students with experience in neuroscience should be aware that the first 2 weeks will cover basic neuroscience.

Students should already be familiar with concepts such as:

Probability -- independence, conditional probability, Bayes rule, multivariate Gaussian distribution, Poisson distribution, Poisson process

Linear algebra -- basic matrix operations (sums and products), matrix inversion, eigenvectors and eigenvalues, singular value decomposition

For those unfamiliar with the concepts above, I would recommend *Probability Theory and Random Processes* (36-217).

If you are unsure whether this class is for you, please talk with me.

Graduate Course Area: Signal Processing and Communications

Class Schedule:

Lecture:
Tuesdays & Thursdays, 2:00 – 3:20pm
Posner A35

Required Textbook:
Pattern Recognition and Machine Learning
Christopher Bishop. Springer, 2007

Optional textbooks:
Principles of Neural Science
Eric Kandel, James Schwartz, Thomas Jessell. McGraw-Hill Medical, 2000.

Theoretical Neuroscience
Peter Dayan and L.F. Abbott. MIT Press, 2001.

Information Theory, Inference, and Learning Algorithms
David J.C. MacKay. Cambridge University Press, 2003.

Matlab for Neuroscientists
Pascal Wallisch, Michael Lusignan, Marc Benayoun, Tanya I. Baker, Adam S. Dickey, and Nicholas G. Hatsopoulos. Academic Press, 2009.

Assignments and exams:
There will be approximately 8 problem sets during the semester and regular reading assignments. There will be a midterm exam in class on **Thursday, March 2** and a final exam during the week May 1-5, date TBD.

Most problem sets will have a Matlab component, in which students will implement various algorithms and apply them to neural data. This link has information about how to obtain Matlab software: https://www.cmu.edu/computing/software/all/matlab/

Students may discuss problem sets, but each student must turn in his/her own work. *You may not simply copy another student's work.* All students are bound by the CMU Academic Integrity Code (see below).

Late policy for problem sets: Each student is allowed two late problem sets during the semester (up to 24 hours after the deadline). Problem sets that are turned in outside of this grace period will receive zero credit.

Grading breakdown:

Problem sets 30%
Midterm exam 30%
Final exam 40%

Course Outline:

1. What is neural signal processing?
   (1 lecture)
2. Neuroscience basics. Membrane potential. Action potential. Synaptic transmission.
   (4 lectures)
   PNS Ch 1, 2, 7
   Excerpts from PNS Ch 9, 10, 12
3. Spike train analysis. Spike histogram. Tuning curve. Poisson process.
   (4 lectures)
   TN Ch 1
4. Classification. Naive Bayes.
   Neuroscience application: discrete neural decoding
   (3 lectures)
   PRML Ch 4
5. Graphical models.
   (1 lecture)
   PRML Ch 8.1-8.2
6. Mixture models. Expectation-maximization.
   Neuroscience application: spike sorting
   (4 lectures)
   PRML Ch 9
7. Model selection. Cross-validation.
   Neuroscience applications: spike sorting, dimensionality reduction
   (2 lectures)
   PRML Ch 1.3, 3.4
8. Principal components analysis. Factor analysis.

Neuroscience applications: spike sorting, dimensionality reduction
(4 lectures)
PRML Ch 12

9. Kalman filter.
   Neuroscience application: continuous neural decoding
   (2 lectures)
   PRML Ch 13

Education Objectives (Relationship of Course to Program Outcomes)

The ECE department is accredited by ABET to ensure the quality of your education. ABET defines 7 Educational Objectives that are fulfilled by the sum total of all the courses you take. The following list describes which objectives are fulfilled by 18-698/42-632 and in what manner they are fulfilled. The objectives are numbered from "1" through "7" in the standard ABET parlance. Those objectives not fulfilled by 18-698 have been omitted from the following list.

(1) **An ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics**: The course poses many problems on homeworks and during exams for the student to formulate and solve using good engineering practice. The student will use mathematical and engineering concepts to design signal processing algorithms for neuroscience applications.

(2) **An ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors**: The course discusses how biomedical systems to improve human health, in particular those that interface with the nervous system, can be designed using the signal processing algorithms covered.

(3) **An ability to communicate effectively with a range of audiences**: Students practice their communication skills in homeworks and exams, where they learn to plot data and results of their analyses in a way that can be easily digested by a broad audience.

(5) **An ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives**: Students are encouraged to discuss with their classmates before writing up their own work.

(6) **An ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgment to draw conclusions**: Homeworks in this course involve interpreting the output of signal processing algorithms when they are applied to neural data. Students will interpret the results in the context of brain function and biomedical system design.

(7) **An ability to acquire and apply new knowledge as needed, using appropriate learning strategies**: Students learn the fundamentals of more advanced methods outside

the scope of this course, which they may encounter in future work and need to learn on their own.

ECE Academic Integrity Policy:

The Department of Electrical and Computer Engineering adheres to the academic integrity policies set forth by Carnegie Mellon University and by the College of Engineering. ECE students should review fully and carefully Carnegie Mellon University's policies regarding Cheating and Plagiarism; Undergraduate Academic Discipline; and Graduate Academic Discipline. ECE graduate student should further review the Penalties for Graduate Student Academic Integrity Violations in CIT outlined in the CIT Policy on Graduate Student Academic Integrity Violations. In addition to the above university and college-level policies, it is ECE's policy that an ECE graduate student may not drop a course in which a disciplinary action is assessed or pending without the course instructor's explicit approval. Further, an ECE course instructor may set his/her own course-specific academic integrity policies that do not conflict with university and college-level policies; course-specific policies should be made available to the students in writing in the first week of class.

This policy applies, in all respects, to this course.

CMU Academic Integrity Policy (http://www.cmu.edu/academic-integrity/index.html**):**

In the midst of self exploration, the high demands of a challenging academic environment can create situations where some students have difficulty exercising good judgment. Academic challenges can provide many opportunities for high standards to evolve if students actively reflect on these challenges and if the community supports discussions to aid in this process. It is the responsibility of the entire community to establish and maintain the integrity of our university.

This site is offered as a comprehensive and accessible resource compiling and organizing the multitude of information pertaining to academic integrity that is available from across the university. These pages include practical information concerning policies, protocols and best practices as well as articulations of the institutional values from which the policies and protocols grew. The Carnegie Mellon Code, while not formally an honor code, serves as the foundation of these values and frames the expectations of our community with regard to personal integrity.

This policy applies, in all respects, to this course.

The Carnegie Mellon Code

Students at Carnegie Mellon, because they are members of an academic community dedicated to the achievement of excellence, are expected to meet the highest standards of personal, ethical and moral conduct possible.

These standards require personal integrity, a commitment to honesty without compromise, as well as truth without equivocation and a willingness to place the good of

the community above the good of the self. Obligations once undertaken must be met, commitments kept.

As members of the Carnegie Mellon community, individuals are expected to uphold the standards of the community in addition to holding others accountable for said standards. It is rare that the life of a student in an academic community can be so private that it will not affect the community as a whole or that the above standards do not apply.

The discovery, advancement and communication of knowledge are not possible without a commitment to these standards. Creativity cannot exist without acknowledgment of the creativity of others. New knowledge cannot be developed without credit for prior knowledge. Without the ability to trust that these principles will be observed, an academic community cannot exist.

The commitment of its faculty, staff and students to these standards contributes to the high respect in which the Carnegie Mellon degree is held. Students must not destroy that respect by their failure to meet these standards. Students who cannot meet them should voluntarily withdraw from the university.

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Cheating states the following:

According to the University Policy on Academic Integrity, cheating "occurs when a student avails her/himself of an unfair or disallowed advantage which includes but is not limited to:

- Theft of or unauthorized access to an exam, answer key or other graded work from previous course offerings.
- Use of an alternate, stand-in or proxy during an examination.
- Copying from the examination or work of another person or source.
- Submission or use of falsified data.
- Using false statements to obtain additional time or other accommodation.
- Falsification of academic credentials."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Plagiarism states the following:

According to the University Policy on Academic Integrity, plagiarism "is defined as the use of work or concepts contributed by other individuals without proper attribution or citation. Unique ideas or materials taken from another source for either written or oral use must be fully acknowledged in academic work to be graded. Examples of sources expected to be referenced include but are not limited to:

- Text, either written or spoken, quoted directly or paraphrased.
- Graphic elements.
- Passages of music, existing either as sound or as notation.

- Mathematical proofs.
- Scientific data.
- Concepts or material derived from the work, published or unpublished, of another person."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Unauthorized Assistance states the following:

According to the University Policy on Academic Integrity, unauthorized assistance "refers to the use of sources of support that have not been specifically authorized in this policy statement or by the course instructor(s) in the completion of academic work to be graded. Such sources of support may include but are not limited to advice or help provided by another individual, published or unpublished written sources, and electronic sources. Examples of unauthorized assistance include but are not limited to:

- Collaboration on any assignment beyond the standards authorized by this policy statement and the course instructor(s).
- Submission of work completed or edited in whole or in part by another person.
- Supplying or communicating unauthorized information or materials, including graded work and answer keys from previous course offerings, in any way to another student.
- Use of unauthorized information or materials, including graded work and answer keys from previous course offerings.
- Use of unauthorized devices.
- Submission for credit of previously completed graded work in a second course without first obtaining permission from the instructor(s) of the second course. In the case of concurrent courses, permission to submit the same work for credit in two courses must be obtained from the instructors of both courses."

This policy applies, in all respects, to this course.

Carnegie Mellon University's Policy on Research Misconduct states the following:

According to the University Policy For Handling Alleged Misconduct In Research, “Carnegie Mellon University is responsible for the integrity of research conducted at the university. As a community of scholars, in which truth and integrity are fundamental, the university must establish procedures for the investigation of allegations of misconduct of research with due care to protect the rights of those accused, those making the allegations, and the university. Furthermore, federal regulations require the university to have explicit procedures for addressing incidents in which there are allegations of misconduct in research.”

The policy goes on to note that “misconduct means:

- fabrication, falsification, plagiarism, or other serious deviation from accepted practices in proposing, carrying out, or reporting results from research;

- material failure to comply with Federal requirements for the protection of researchers, human subjects, or the public or for ensuring the welfare of laboratory animals; or

- failure to meet other material legal requirements governing research."

"To be deemed misconduct for the purposes of this policy, a 'material failure to comply with Federal requirements' or a 'failure to meet other material legal requirements' must be intentional or grossly negligent."

To become familiar with the expectations around the responsible conduct of research, please review the guidelines for Research Ethics published by the Office of Research Integrity and Compliance.

This policy applies, in all respects, to this course.

Take care of yourself. Do your best to maintain a healthy lifestyle this semester by eating well, exercising, avoiding drugs and alcohol, getting enough sleep and taking some time to relax. This will help you achieve your goals and cope with stress.

All of us benefit from support during times of struggle. You are not alone. There are many helpful resources available on campus and an important part of the college experience is learning how to ask for help. Asking for support sooner rather than later is often helpful.

If you or anyone you know experiences any academic stress, difficult life events, or feelings like anxiety or depression, we strongly encourage you to seek support. Counseling and Psychological Services (CaPS) is here to help: call 412-268-2922 and visit their website at http://www.cmu.edu/counseling/. Consider reaching out to a friend, faculty or family member you trust for help getting connected to the support that can help.

If you have questions about this or your coursework, please let me know.