Harvard University
School of Engineering and Applied Sciences

ENG-SCI 157: Biological Signal Processing

Fall 2020

Course Information

Course information

Instructor:
Demba Ba. (demba@seas.harvard.edu)
33 Oxford st, Room MD-143
Cambridge, MA 02138
(617) 495-1228 [Voice]
Office Hours: T/Th 4:00-5:00 PM and by appointment (Zoom ID/pwd: TBD).

Teaching Fellow:
Manos Theodosis. (ethodosis@college.harvard.edu)
Section: TBD (Zoom ID/pwd: TBD).
Office Hours: TBD (Zoom ID/pwd: TBD).

Lecture:
T-Th 10:30-11:45 AM (Zoom ID/pwd: TBD)
Course Administrator:
Gioia Sweetland. (gioia@seas.harvard.edu)

Course Website:
`https://canvas.harvard.edu/courses/77426/`

Course overview

This is the first course on Biological Signal Processing, the science of collection, representation, manipulation, transformation, storing of **biological signals**, *and* the use of **modern scientific computing tools** (Python, Jupyter notebooks) to interpret biological signals and tell engaging and informative stories using biological data. We will use EEG, EKG, temperature data, neural spiking data, and data from Covid-19 as examples. Our focus will be on foundational signal processing concepts that can be applied in a variety of biological applications. Examples include the Fourier Transform, Principal Component Analysis, Clustering, etc. Applications include those to patient monitoring, diagnostics, patient prognostics, online monitoring, and the computation of wellness measures. We will introduce you to a powerful suite of mathematical and scientific computing tools will enable you to evaluate and make decisions based on evidence and data.

Remote-teaching Plan

Lecture: For every lecture, the instructor will record two 20-minute videos of himself delivering the contents of the lecture on a board. The instructor will post these a few days before the lecture. The instructor asks that you watch each video and prepare one question (or more). During class time, we will get together for 40 minutes. First, the instructor will summarize the videos. Then, we will solve examples from lecture together in break-out rooms. Finally, we will all come back together and have a Q&A session.
Instructor's Office Hours: There will be two sets of office hours. During each, we will have a break-out room associated with each problem on the problem set out at the time. The instructor will rotate across break-out rooms.

1. Hour 1: (Problem deconstruction) During this hour, you will learn how to attack and approach problems by asking us and each other questions. We ask that you do not attempt to solve the problems during this time.

2. Hour 2: (Problem solving) During this hour, you will have the opportunity to collaborate and solve problems together.

Section: Section will last one hour and consist of two parts. During the first part, you will practice implementing some of the material from class using Juypter notebooks we will prepare in advance. During the second part, you will solve problems with the TF. As in lecture, the TF will use break-out rooms to foster a collaborative environment.

Prerequisites

The official prerequisites for this course are APPLIED MATH 21a or MATH 21a. In general what this course will require is a basic level of mathematical maturity. We will try to cover all the required background nonetheless. In particular, it does not hurt if you know how to manipulate complex numbers, and know about matrices.

Textbook

Biomedical Signal Analysis, by Fabian J. Theis and Anke Meyer-Base, The MIT Press, Cambridge, MA.

You can find the textbook in the HOLLIS catalog as a networked electronic resource. You decide whether you would like to purchase a hardcopy of the book. We we will post electronic versions of my lecture notes on the course website. These may differ substantially from the book. This is because I would like to strike the right balance between biological concepts and signal processing concepts. You are highly encouraged to study my notes.

Policy on collaboration

To get the most out of this course, you are encouraged to struggle with the course assignments on your own and reach out to the course staff during Office Hours. **We encourage you to collaborate on assignments *after* you've spent time on them on your own**.Your write-up of assignments must entirely be your own. Moreover, at the top of every assignment, we ask that you acknowledge the students you have discussed said assignment with. We also ask you to acknowledge the use of books, articles, websites, lectures, discussions, etc., that you have consulted to complete your assignments.

Grading information

The final grade for this course will be based on your performance on problem sets, lab assignments (labs), two examinations and a final project.

1. **Problem sets**: There will be **5 mandatory problem sets** that will count towards **25% of your final grade**. Problem sets will consist of "pen-and-paper assignments" and/or computational assignments. They will be released on the canvas website.

2. **Labs**: There will be **3 mandatory labs** that will count **towards 15% of your final grade**, and a fourth **optional** lab whose completion will earn you an additional **5%** to your final grade. Labs will be released on the canvas website as Jupyter notebooks. They will be due at the beginning of class on the date stated in the course calendar.

3. **Midterms**: There will be **2 examinations** that will each count towards **25% of your final grade**. The midterm examination will cover the material up to and including October 8th 2020. The second examination will primarily test your knowledge of the material covered after October 9th 2020 and a little bit of the material covered prior to that. You will have 24 hours to complete each examination.

4. **Final project**: The **final project** will count towards **10% of your final grade**. The goal of the final project is to apply the tools from class to Covid-19-related data. We ask that you put together a short one-page project proposal to be discussed with the course staff following its submission (see course calendar). The grade will be based, not on the quality of your results, but on your proposal, your ability to apply the concepts and tools taught in class in a deliberate, goal-oriented manner. We encourage you to work in pairs, though you may choose to work alone.

   Examples of Covid-19 related projects:

- Use the Fourier transform to analyze the frequency content of the daily number-of-positive-cases (NOPCs) data from your country/state/city/locality. Find another locality to compare to. Interpret what you find.
- Apply the Kalman and binomial filters to daily NOPCs and daily number-of-tests (NOTs) data. How does the probability of a positive case evolve over time? Compare to data from another locality.
- Use data from all the states/provinces in your country to train a classifier for whether the infection rate is high or low in a given state/province.

Note: Problem set 4 and Lab 4 have been designed with the final project in mind. The former requires the formulation of preliminary project ideas, and the latter asks you to show us the data set you plan to utilize.

Policy on Late Assignments

Except for the exams and the final-project report, you get to turn in two assignments up to three days late, no questions asked. Please contact the instructor if you need an extension on other assignments.

Disclaimer

While the above weights are used for computing the final grade, I reserve my right to scale the grades based on the performance of the entire class. Naturally, this possible scaling will not have an adverse effect on the grades and can only increase the raw grades.

Communication

We will use `slack` to facilitate communication among students and between students and teaching fellows/course assistants. We will invite you to the **es157-students-fall20** slack Team. The instructor is best reached via email.

Table 1: **Course Calendar**

	Date	Topic	Psets/Labs
		Deterministic Signals and Systems	
Th	09/03	Signals and Systems	**Pset 1/Lab 1 out**
T	09/08	Linear Time-Invariant (LTI) Systems	
Th	09/10	Fourier Transform (FT)	
T	09/15	Sampling	
Th	09/17	Discrete Fourier Transform (DFT), Short-time FT (STFT) and filtering	**Lab 1 due, Lab 2 out**
		Stochastic Signals and Systems	
T	09/22	Basic probability	**Pset 1 due, Pset 2 out**
Th	09/24	Maximum Likelihood Estimation	
T	09/29	Basic Linear Algebra	
Th	10/01	Principal Component Analysis (PCA)	**Pset 2 due, Pset 3 out**
T	10/06	Bayes' rule and Maximum A-Posteriori (MAP) Estimation	
Th	10/08	Advanced Topics in Estimation	**Lab 2 due, Lab 3 out**
T	10/13	Kalman filtering I	
Th	10/15	**Kalman filtering II**	**Pset 3 due**
F-M	10/16–10/19	**Take-home Midterm**	
		Advanced topics: ICA, Clustering, Filtering and Smoothing	
T	10/20	Point process filtering and applications	**Pset 4 out**
Th	10/22	Filtering and smoothing	
T	10/27	Guest lecture	
Th	10/29	Two-class Fisher LDA (intro)	**Lab 3 due**
T	11/03	Two-class Fisher LDA and Fisher criterion	**Pset 5 out**
Th	11/05	Probabilistic decision rules/Multi-class LDA	**Project proposal due** **Pset 4 due, Lab 4 out**
T	11/10	Clustering (k-means)	
Th	11/12	ICA, BSS, and Maximization of non-Gaussianity	
T	11/17	ICA and BSS by kurtosis maximization (single source)	
Th	11/19	Finding multiple sources by ICA	**Pset 5 due**
T	11/24		**Project check-in** **Lab 4 due**
Th	11/26	**Break**	
Th	12/01	**Concluding thoughts**	
T	12/03	Student presentations	
S	12/07	**Final project due**	
T	TBD	**Final exam**	