HST582/6.555/16.456 Biomedical Signal and Image Processing HST482/6.026

Spring 2022

Lecture: Tuesday **and** Thursday, 9:30-11am, 56-154
Lab: Wednesday 10am-noon **or** Friday 10am-noon, 56-154, with considerable flexibility

Staff

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Overview
This course presents the fundamentals of digital signal processing with emphasis on problems in biomedical research and clinical medicine. It covers basic principles and algorithms for processing both deterministic and random signals. Topics include data acquisition, imaging, filtering, coding, feature extraction, and modeling. The focus of the course is a series of MATLAB® lab exercises that provide practical experience with cardiologic data, speech signals, and medical images. Lectures cover signal processing topics relevant to the lab exercises, as well as background on the physiological signals processed in the labs.

Values
In this class, we aim to serve a diverse community of students by creating an inclusive and supportive learning environment. Collectively, our behavior and actions should always reflect MIT's shared values of excellence, openness, integrity, and mutual respect. Moreover, student well-being is always our first concern; academic accomplishments should never come at the expense of one's mental or physical health. *Please reach out for any reason and let the teaching staff know how we can support you.*

Attendance Policies and COVID
We generally expect students to attend class in person when possible, and to notify us promptly if extenuating circumstances arise. And yes, there are many understandable reasons for missing class during these unprecedented times. As of this writing, we are exploring options to record lectures and make them available as needed. In any case, we are committed to working in partnership with you - and with S3 or GradSupport if applicable - to support your continued learning. We understand that there are multiple challenges and that we all need to remain flexible and adjust to the changing situation. Please reach out with questions/concerns.

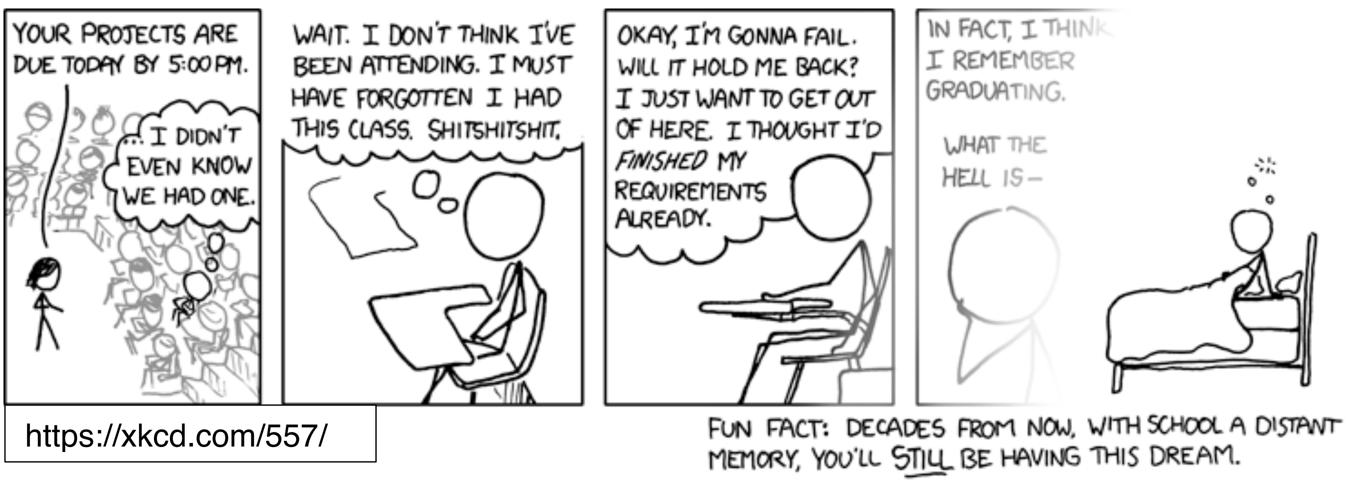
Face Masks
MIT's mask policy is designed to keep students and instructors as safe as possible. In light of this, any person who does not follow the MIT policy will be asked to leave our classroom. If you need to remove your mask for any reason, please feel free to leave the room briefly and find a safe space to do so. You may return to the classroom after your mask is securely in place.

Website and Materials

- The class site on Canvas will be the main repository for all materials.
- The primary text is a series of course notes that will be posted on the Canvas site.
- Optional supplementary textbooks are listed later in this document.

Grading
Final grades are determined based on:
- Problem sets (5) – 20%
- Consolidation exercises – 20%
- Lab reports (5) – 60%

Late Assignments
Requests for extensions beyond the original due date should be made *in advance* via email to 6.555@mit.edu. In your email, please explain the circumstances necessitating the extension and propose a revised due date. (Here are examples of the types of circumstances that will generally be met with sympathy and flexibility: illness, conference travel, interview travel, multiple major assignments due in other classes on the same day.) In the absence of an approved extension, late assignments will be penalized one full point for every two days past the original deadline. Problem sets are graded out of 4 points; labs are graded out of 10 points.



https://xkcd.com/557/

Academic Integrity and Collaboration
When you submit an assignment under your name, you are certifying that it is your own work. Copying the work of others, or knowingly making work available for copying, is a serious offense that may incur reduced grades, failing the course, and disciplinary action. Limited collaboration is permitted on problem sets and lab reports, as described below.

Problem Sets
The goal of the problem sets is to give you practice in mastering the course material. Therefore, we recommend spending time working on each problem independently before seeking help from others. While collaboration with other students is permissible, you should endeavor to limit such collaboration to discussion of approaches/strategies and mutual troubleshooting. It is not acceptable to copy solutions from any source. If you copy solutions, you will have skipped the process of personally struggling with new concepts and lost a valuable learning experience.

Problem sets are graded as follows:
4 - Few to no errors, indicating a thorough understanding of the material.
3 - Some errors, suggesting an adequate understanding of the material.
2 - Numerous errors, suggesting significant gaps in understanding of the material.

1 - Incomplete, that is, some sections not attempted.
0 - Missing or submitted late without prior arrangement.

Problem sets may be submitted by uploading a single PDF file on Canvas by 11:59pm on the due date. Please note:

- Handwritten pages should be scanned if possible. If you must submit photographs, please take care to make them legible and use a scanner app that produces pdfs, for example, GeniusScan, iScanner, etc.
- Files should follow this naming convention:
    - LastName_FirstName_Assignment, for example: Greenberg_Julie_PS1.pdf

Consolidation Exercises

Based on innovations that were originally made during the rapid transition to online learning in spring 2020, this term we will pilot a series of consolidation exercises rather than having quizzes. This will give you an opportunity to review fundamental concepts learned throughout the course, without the high-stakes pressure associated with quizzes. The consolidation exercises will consist of:

- *Two written assignments* - They will be due in March on the dates indicated by CE1 and CE2 in the calendar on the last page of this document;
- *Three in-class activities* - Please be sure to block your calendars for the three April dates indicated in the calendar below.

The consolidation exercises will be graded based on demonstrated knowledge of relevant concepts, participation, and effort. Specific details will be distributed later in the term.

Lab Reports

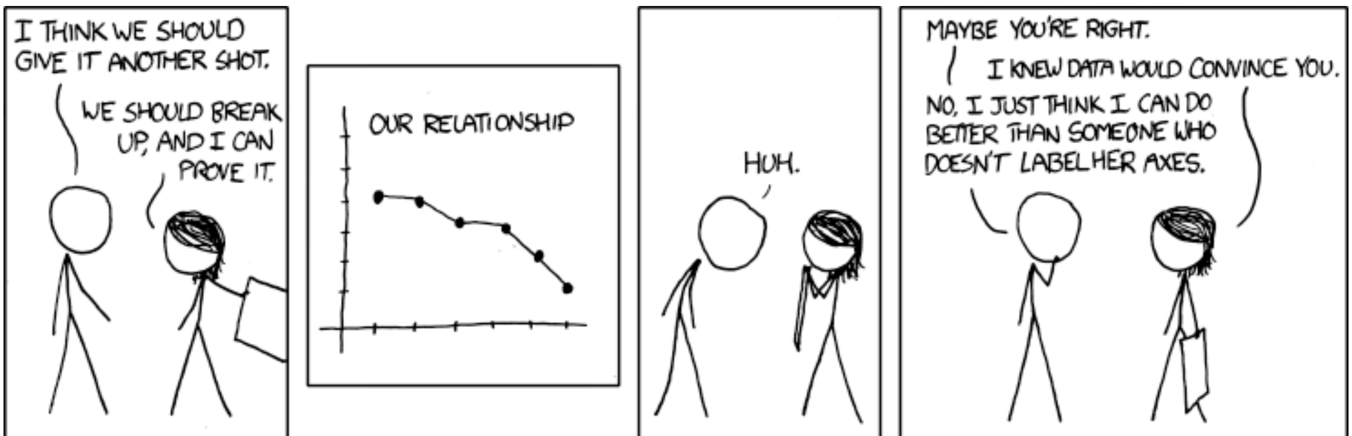
Your lab reports should be produced independently, that is, answering the questions asked in the lab handout on your own, giving your own interpretation of the results, and using your own words.

- In the course of doing the lab exercises, you are encouraged to share ideas and discuss technical approaches with your classmates.
- While each student is expected to write their own MATLAB functions and generate their own figures, it is permissible to give/receive help in debugging code.
- If you have collaborated with other students as described here, you must acknowledge them by name and explain their contribution in response to the last question in the lab handout.
- If you have not collaborated with other students, please include the words *no collaboration* in response to the last question in the lab handout.

Lab reports should be submitted by uploading a single PDF file to Canvas by 11:59pm on the due date. Lab reports should consist of *clear* and *concise* responses to the questions in the lab handout:

- Make sure that each answer is clearly labeled with the corresponding question number.
- Include plots, block diagrams, and flowcharts as appropriate.
- When describing signal processing operations, include the motivation for the signal processing performed and the implementation used to accomplish that processing.
- When describing results of signal processing, refer to relevant figures and then briefly discuss what you identify as their most important features.
- It's not always possible to get things working perfectly. If this should happen, summarize what worked, what didn't work, and what you might have tried if given more time.

- Within the lab report:
    - All figures should be numbered and referred to by number in the text.
    - All figures should have a title.
    - All axes should be labelled.
    - Whenever possible, axis labels should be in real-world units. For example, units of time should be given in sec, not samples; frequency in Hz, not FFT index k.
    - It is strongly preferred that figures be imbedded in the text for ease of grading. Please do not appended figures to the end of the report unless it is absolutely necessary.
- Lab reports should **NOT** include:
    - Text corresponding to sections other than the numbered questions. For example, do not include an introduction section or conclusions.
    - MATLAB commands or MATLAB code, unless specifically requested in the lab handout.



https://xkcd.com/833/

Lab Topics

- **Filtering and Frequency Analysis of the Electrocardiogram:** Design filters to remove noise from electrocardiogram (ECG) signals and then design a system to detect life-threatening ventricular arrhythmias. The detector is tested on normal and abnormal ECG signals. (3 weeks)
- **Speech Coding**: Implement, test, and compare two speech analysis-synthesis systems that each utilize a pitch detector and a speech synthesizer based on the source-filter model of speech production. (3 weeks)
- **Image Registration**: Explore the co-registration of medical images, focusing on 2-D to 2-D (slice to slice) registration and using non-linear optimization methods to maximize various measures of image alignment. (2 weeks)
- **ECG: Blind Source Separation:** Separate fetal and maternal ECG signals using techniques based on higher-order statistical methods. Techniques include Wiener filtering, principal component analysis, and independent component analysis. (2 weeks)
- **Image Segmentation**: Process clinical MRI scans of the human brain to reduce noise, label tissue types, extract brain contours, and visualize 3-D anatomical structures. (2 weeks)

Lecture Topics

- **Data Acquisition**: Sampling in time, aliasing, interpolation, and quantization.
- **Digital Filtering**: Difference equations, FIR and IIR filters, basic properties of discrete-time systems, convolution.
- **ECG Signals**: Cardiac electrophysiology, relation of electrocardiogram (ECG) components to cardiac events, clinical applications.
- **DTFT**: Discrete-time Fourier transform and its properties. FIR filter design using windows.
- **DFT**: Discrete Fourier transform and its properties, fast Fourier transform (FFT), overlap-save algorithm, digital filtering of continuous-time signals.
- **Sampling Revisited**: Sampling and aliasing in time and frequency, spectral analysis.
- **Speech Signals**: Source-filter model of speech production, spectrographic analysis of speech.
- **Speech Coding**: Analysis-synthesis systems, channel vocoders, linear prediction of speech, linear prediction vocoders
- **Image Processing**: Extension of filtering and Fourier methods to 2-D signals and systems.
- **Radiology for Engineers**: Overview medical imaging modalities including X-ray, fluoroscopy, ultrasound, CT, MRI, PET/nuclear medicine.
- **Image Registration I and II**: Rigid and non-rigid transformations, objective functions, joint entropy, optimization methods.
- **Probability**: Random variables, probability density functions, expected value, joint probability density functions, conditional probabilities, Bayes' rule.
- **Random signals I**: Time averages, ensemble averages, autocorrelation functions, crosscorrelation functions.
- **Random signals II**: Random signals and linear systems, power spectra, cross spectra, Wiener filters.
- **Blind source separation**: Use of principal component analysis (PCA) and independent component analysis (ICA) for filtering.
- **Hypothesis Testing I**: Bayesian hypothesis testing, decision rules, likelihood ratio test, maximum likelihood decision rule, risk adjusted classifiers.
- **Hypothesis Testing II**: Non-Bayesian hypothesis testing, receiver operating characteristic (ROC) curves.
- **Image Segmentation:** Statistical classification, morphological operators, connected components.
- **MR Physics:** *(tentative)* Physics and signal processing for magnetic resonance imaging.
- **Diffusion Tensor MRI of the Heart:** *(tentative)* Basics of diffusion MR, cardiac microstructural architecture, self-diffusion tensor reconstruction and image processing, and bulk motion correction co-registration, with applications to bio-inspired device design and therapy response.
- **Image Guided Therapy:** *(tentative)* Survey of algorithms and technologies used to enhance medical procedures and improve patient care.

Optional Supplementary Texts

General
- Oppenheim and Schafer (2009). Discrete-time Signal Processing, Prentice-Hall.
- Oppenheim, Willsky and Nawab (2001). Signals and Systems. Prentice Hall.
- Smith (2002). Digital Signal Processing: A Practical Guide for Engineers and Scientists, Elsevier Science & Technology Books (http://www.dspguide.com/pdfbook.htm).
- Karu (1995). Signals and Systems Made Ridiculously Simple. ZiZi Press.
- Buck, Daniel, and Singer (2001). Computer Explorations in Signals and Systems Using MATLAB. Prentice Hall.

Probability and Classification
- Duda, Hart and Stork (2000). Pattern classification. Wiley.
- Bishop (1996). Neural Networks for Pattern Recognition, Oxford University Press.
- Nabney (2004). Netlab: Algorithms for Pattern Recognition, Springer.
- Gubner (2006). Probability and Random Processes for Electrical and Computer Engineers, Cambridge University Press.

ECG Analysis
- Azuaje, Clifford, and McSharry (2006). Advanced Methods and Tools for ECG Data Analysis, Artech House (https://mit-library.skillport.com/skillportfe/main.action?assetid=27221).

Speech
- Rossing, Moore, and Wheeler (2001). The Science of Sound, Addison Wesley.
- Quatieri (2001). Discrete-Time Speech Signal Processing: Principles and Practice, Prentice Hall. *Out of print*

Image Processing and Medical Imaging
- Lim (1989). Two-Dimensional Signal and Image Processing, Prentice Hall. *Out of print*
- Gonzalez and Woods (2017). Digital Image Processing, Pearson Education.
- Epstein (2007). Introduction to the Mathematics of Medical Imaging, Society for Industrial and Applied Mathematics.
- Webb (2012). Webb's Physics of Medical Imaging, Taylor & Francis Group.
- Westbrook, Roth, and Talbot (2018). MRI in Practice, Wiley & Sons.
- Macovski (1997). Medical Imaging Systems, Prentice Hall.

	Monday	Tuesday	Wednesday	Thursday	Friday
February	**31**	**1** Lec 1: Data Acquisition (JG)	**2** No Lab	**3** Lec 2: ECG Signal (guest) *PS1 out*	**4** Lab 0: Intro to Matlab
	7	**8** Lec 3: Digital Filtering (JG) *Lab 1 out*	**9** Lab 1A: ECG	**10** Lec 4: DTFT (JG) ***PS1 due****/PS2 out*	**11** Lab 1A: ECG
	14	**15** Lec 5: DFT (JG)	**16** Lab 1B: ECG	**17** Lec 6: Sampling Revisited (JG) ***PS2 due****/PS3 out*	**18** Lab 1B: ECG
	21 *Holiday*	**22** *Monday class schedule*	**23** Lab 1C: ECG	**24** Lec 7: Speech Signals (JG) ***PS3 due***	**25** Lab 1C: ECG
March	**28**	**1** Lec 8: Speech Coding (JG) ***Lab 1 due****/Lab 2 out*	**2** Lab 2A: Speech	**3** Lec 9: Image Processing (JG) *CE 1 & CE 2 out*	**4** Lab 2A: Speech
	7	**8** Lec 10: Radiology for Engineers (AT)	**9** Lab 2B: Speech	**10** Lec 11: Image Registration I (DI) ***CE 1 due***	**11** Lab 2B: Speech
	14	**15** Lec 12: Image Registration II (DI)	**16** Lab 2C: Speech	**17** Lec 13: Probability (JG) ***CE 2 due***	**18** Lab 2C: Speech
	March 21-25: MIT Spring Break				
April	**28**	**28** Lec 14: Random Signals I (JG) ***Lab 2 due****/Lab 3 out*	**30** Lab 3A: Image Registration	**31** Lec 15: Random Signals II (JG) *PS 4 out*	**1** Lab 3A: Image Registration
	4	**5** Lec 16: Hypoth. Testing I (JG)	**6** Lab 3B: Image Registration	**7** Lec 17: Hypoth. Testing II (JG) ***PS 4 due****/PS5 out*	**8** Lab 3B: Image Registration
	11	**12** Lec 18: Blind Source Separation (guest) ***Lab 3 due/*** *Lab 4 out*	**13** Lab 4A: Blind Source Separation	**14** Not Lec 19: Consolidation Exercise – Part I (KK) ***PS 5 due***	**15** Lab 4A: Blind Source Separation
	18 *Holiday*	**19** Not Lec 20: Consolidation Exercise – Part II	**20** Lab 4B: Blind Source Separation	**21** Not Lec 21: Consolidation Exercise – Part III	**22** Lab 4B: Blind Source Separation
	25	**26** Lec 22: Image Segmentation (KK) ***Lab 4 due/*** *Lab 5 out*	**27** Lab 5A: Image Segmentation	**28** Lec 23: MR Physics (guest)	**29** Lab 5A: Image Segmentation
May	**2**	**3** Lec 24: Cardiac DT-MRI (guest)	**4** Lab 5B: Image Segmentation	**5** Lec 25: Image Guided Therapy (guest)	**6** Lab 5B: Image Segmentation
	9	**10** Lec 26: Last Class (JG) ***Lab 5 due***	**11**	**12**	**13**