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

Spring 2020

Time and Location
Lecture: Tuesday **and** Thursday, 9:30-11am, MIT Room 56-154
Lab: Wednesday **or** Friday, 10am-1pm, with considerable flexibility, MIT Room 1-115

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, a student's well-being is always our first concern; academic accomplishments should never come at the expense of one's mental or physical health.

Snow Closings
In the event that MIT closes due to extreme weather conditions, please watch your email for additional instructions. In recent years we have held class via WebEx at the regularly scheduled time during snowstorms.

Materials and Website

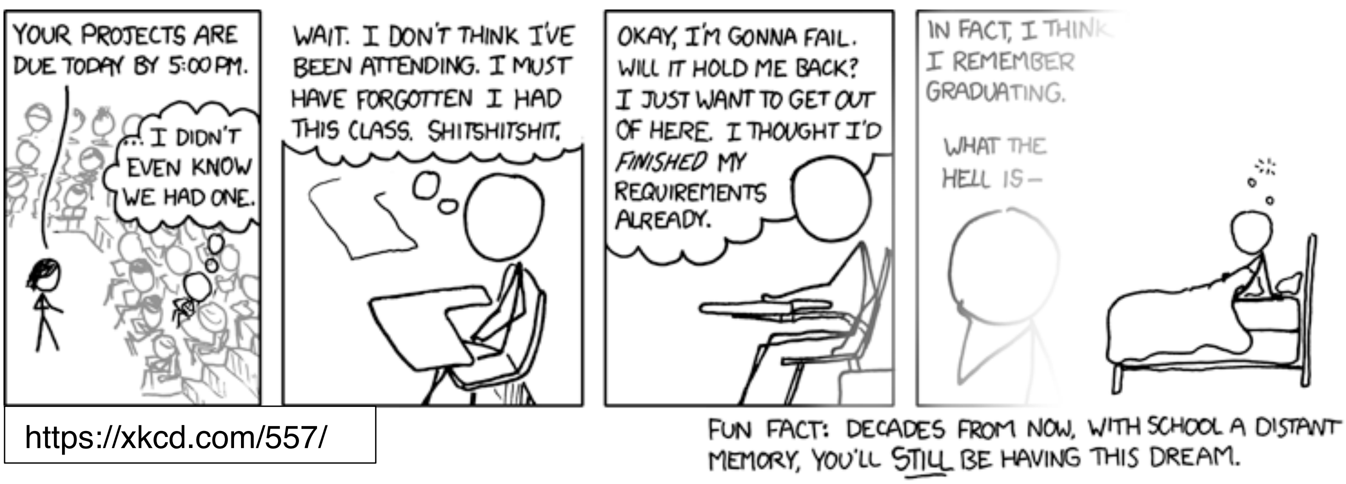
All course materials are posted to the class website, and registered students should automatically have access:

https://learning-modules.mit.edu/class/index.html?uuid=/course/6/sp20/6.555

Please contact 6.555@mit.edu if you need assistance. The primary text for this class is a series of course notes that are distributed in class and posted on the class website. Optional supplementary textbooks are listed later in this document.

Grading
Final grades are determined based on:
5 lab reports – 60%
2 quizzes – 25%
5 problem sets – 10%
Class participation and effort – 5%

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.



https://xkcd.com/557/

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.[1] 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.)

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. No collaboration whatsoever is permitted on quizzes. Limited collaboration is permitted on problem sets and lab reports, as described below.

[1] Here are some 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.

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 may be submitted either on paper at the beginning of class on the due date OR by uploading a single PDF file to the Stellar/Learning Modules website by 11:59pm on the due date. *Please do NOT submit both hard copy and electronic versions of the same assignment*. For electronic submissions, please note:

- Handwritten pages must be scanned; photographs are not acceptable.
- Electronic files should follow this naming convention:
  - LastName_FirstName_Assignment, for example: Greenberg_Julie_PS1.pdf

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 the Gradescope website 11:59pm on the due date. Further instructions will be provided later in the semester.

Lab reports should consist of *clear* and *concise* responses to the questions in the lab handout:

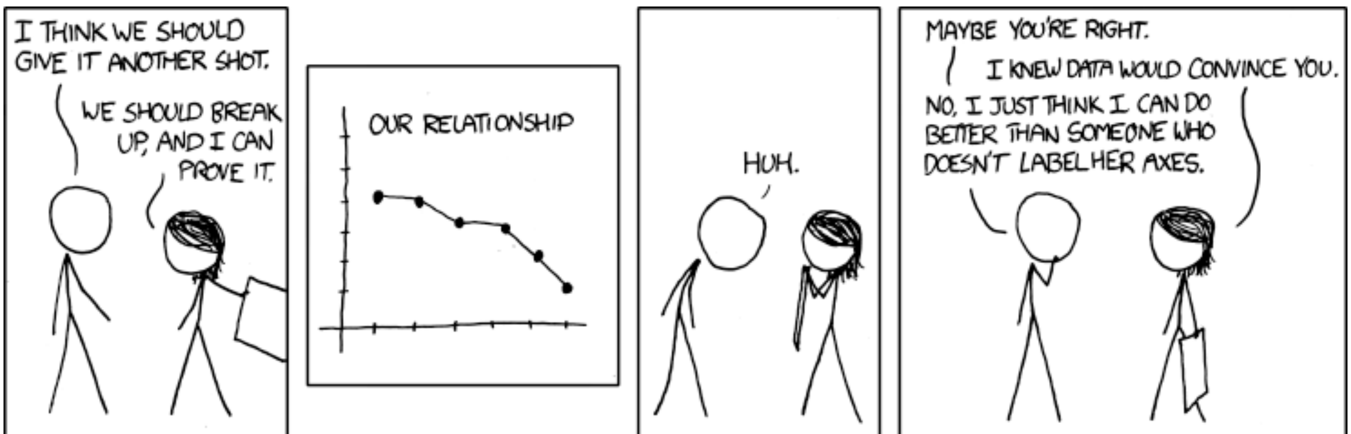
- Make sure that each answer is clearly labeled with the corresponding question number.
- Include plots, block diagrams, and flowcharts as appropriate.
- When describing signal processing operations, include the motivation for the signal processing performed and the implementation used to accomplish 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.

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.

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.



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.
- **Computed Tomography:** Basics of tomography with examples, radon transform, filtered back projection
- **MR Physics**: Physics and signal processing for magnetic resonance imaging.
- **Diffusion Imaging Tractography for Neurosurgery**: Basics of diffusion imaging, white matter anatomy, and diffusion tractography image processing, with applications to neurosurgery. *(tentative)*
- **Image Guided Therapy**: Survey of image processing methods used to enhance medical procedures and improve patient care. *(tentative)*

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.

Image Processing and Medical Imaging
- Lim (1989). Two-Dimensional Signal and Image Processing, Prentice Hall.
- 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 (2011). MRI in Practice, Wiley & Sons.
- Macovski (1997). Medical Imaging Systems, Prentice Hall.

	Monday	Tuesday	Wednesday	Thursday	Friday
	3 *Reg Day*	**4** Lecture 1: Data Acquisition (JG)	**5** No Lab	**6** Lecture 2: Digital Filtering (JG) *PS1 out*	**7** Lab 0: Intro to Matlab
February	**10**	**11** Lecture 3: ECG Signal (guest) *Lab 1 out*	**12** Lab 1A: ECG	**13** Lecture 4: DTFT (JG) ***PS1 due****/PS2 out*	**14** Lab 1A: ECG
	17 *Holiday*	**18** *Monday schedule*	**19** Lab 1B: ECG	**20** Lecture 5: DFT (JG) ***PS2 due****/PS3 out*	**21** Lab 1B: ECG
	24	**25** Lecture 6: Sampling Revisited (JG)	**26** Lab 1C: ECG	**27** Lecture 7: Speech Signals (JG) ***PS3 due***	**28** Lab 1C: ECG
	2	**3** Lecture 8: Speech Coding (JG) ***Lab 1 due****/Lab 2 out*	**4** Lab 2A: Speech	**5** Lecture 9: Image Processing (JG) *PSX out*	**6** Lab 2A: Speech *Add Date*
March	**9**	**10** Lecture 10: Radiology for Engineers (AT) *PSX Solutions out*	**11** Lab 2B: Speech	**12** Lecture 11: Image Registration I (DI)	**13** Lab 2B: Speech
	16	**17** Not Lecture 12: ***Quiz 1***	**18** Lab 2C: Speech	**19** Lecture 13: Image Registration II (DI)	**20** Lab 2C: Speech
	March 23-27: MIT Spring Break				
	30	**31** Lecture 14: Probability (JG) ***Lab 2 due****/Lab 3 out*	**1** Lab 3A: Image Registration	**2** Lecture 15: Random Signals I (JG) *PS4 out*	**3** Lab 3A: Image Registration
	6	**7** Lecture 16: Random Signals II (JG)	**8** Lab 3B: Image Registration	**9** Lecture 17: Hypothesis Testing I (JG) ***PS4 due***	**10** Lab 3B: Image Registration
April	**13** *Holiday*	**14** Lecture 18: Hypothesis Testing II (JG) ***Lab 3 due****/Lab 4 out*	**15** Lab 4A: Blind Source Separation	**16** Lecture 19: Blind Source Separation (guest) *PS5 out*	**17** Lab 4A: Blind Source Separation
	20	**21** Lecture 20: Image Segmentation (SW) *Drop Date*	**22** Lab 4B: Blind Source Separation	**23** Lecture 21: TBD (guest) ***PS5 due****/PSY out*	**24** Lab 4B: Blind Source Separation
	27	**28** Lecture 22: Computed Tomography (AT) ***Lab 4 due****/Lab 5 out*	**29** Lab 5A: Image Segmentation	**30** Lecture 23: TBD (guest) *PSY Solutions out*	**1** Lab 5A: Image Segmentation
May	**4**	**5** Lecture 24: TBD (guest)	**6** Lab 5B: Image Segmentation	**7** Not Lecture 25: ***Quiz 2***	**8** Lab 5B: Image Segmentation
	11	**12** Lecture 26: Last Class (JG) ***Lab 5 due***	**13**	**14**	**15**