ECE 6250: Advanced Topics in Digital Signal Processing
Fall 2019 Syllabus

Summary

ECE 6250 is a general purpose, advanced DSP course designed to follow an introductory DSP course. The central theme of the course is the application of tools from linear algebra to problems in signal processing. Upon successful completion of this course you should be able to:

- describe a range of signal processing problems using the language of bases and vector spaces,
- use the singular value decomposition to solve and analyze a range of least-squares problems,
- efficiently compute the solutions to least-squares problems in structured/large-scale systems.

Prerequisites

An introductory course in digital signal processing covering concepts such as Fourier transforms, filtering, and sampling. Students should also be familiar with the fundamentals of linear algebra and should be very comfortable with the use of matrices to represent systems of equations – some existing familiarity with eigenvalues, eigenvectors, and eigenvalue decompositions will be extremely helpful. While most of the course will adopt a deterministic perspective, many of the models and algorithms we will discuss also have alternative probabilistic interpretations, and hence familiarity with the basics of probability (especially random vectors) will be useful for gaining a deeper appreciation for the material. Finally, students should also have basic MATLAB programming skills.

Instructor

Mark Davenport
Email: mdav@gatech.edu
Office: Coda S1117
Office hours: Tuesdays 2–3pm in Coda C1103 (Lindberg). Also available by appointment.

Teaching Assistant

TBD

Lecture

Lectures are Mondays and Wednesdays from 3:00-4:15pm in Klaus 2443.

Lecture attendance is mandatory and will count towards your grade.

Grading

Your grade will be based on the following factors, with the following allocations:

- **Homework (30%):** There will be 12 homework assignments. See further details below.
- **Quiz #1 (20%):** Tentatively scheduled for September 23.
- **Quiz #2 (20%):** Tentatively scheduled for October 28.
- **Final exam (25%):** The final exam will be comprehensive and will occur at the designated time during the finals period: **December 6, 2:40pm–5:30pm**.
- **Participation (5%):** This is based on my assessment of your engagement in the course. This will be based on factors such as attendance/completion of in-class assignments, participation in classroom discussions, and engagement during office hours and/or on Piazza.

Your final grade will be assigned as a letter grade according to the scale:

A: 90-100% B: 80-89% C: 70-79% D: 60-69% F: $\leq$ 59%

I may exercise the option to "curve" exam scores as necessary (by adjusting the grades higher, but not lower) if I determine that an exam was more difficult than I intended.

Homework

Homework will be assigned weekly (approximately). **Homework will be turned in at the beginning of lecture. Late homework will get zero credit.** Each homework assignment will be graded out of 100 points. Over the course of the semester, **the maximum number of homework points that you can earn is** 1 100 – this serves a similar role to allowing you to drop one homework assignment, but should encourage you to still submit a partially completed one (and avoid panic if there is occasionally a problem that you do not finish in time.) Finally, as per Institute policy, I am required to inform you on the syllabus that **there will be a homework assignment due during the final instruction days of December 2-3**.

The homework assignments will be hard; many of them will require significant amounts of time and effort to complete. But this is really where most of the learning takes place. You will get out of the assignments what you put into them. Students who complete all of the assignments in full will be rewarded with a deep understanding of the role that linear algebra plays in modern signal processing (among other things).

Effectively, homework is worth much more than 30% of your grade. In teaching many graduate courses over the years, **neither instructor has ever seen a case where a student does not put effort into the homework assignments but does well on the exams**.

Distance learning

Distance learning students (Sections Q and QSZ) will be required to complete the same assignments as the on-campus students. The homeworks will be due at the same time for distance and on-campus students. Distance students will have a delay of up to one week to complete the quizzes/exams.

Course materials

The course webpage is at: mdav.ece.gatech.edu/ece-6250-fall2019. This page will provide general course information, copies of the lecture notes, and homework assignments. Homework assignments and solutions will also be posted in canvas, as they become available.

I also plan to make exclusive use of Piazza to make announcements and answer questions. This site can be accessed via: piazza.com/gatech/fall2019/ece6250/home. Piazza is a great platform to discuss problems, find study groups, etc. Please direct any questions you might have to Piazza. Unless your questions are personal in nature, please do not make private posts – if you have a question you are probably not the only one, and other students may benefit from seeing the discussion.

As this course also has an online enrollment, all of my lectures are being recorded. These lectures will be made available to the on-campus students as well. I am providing access to the recorded lectures because they might be useful as study materials and to help out when reviewing material or if missing class is unavoidable. I am *not* meaning to suggest that you can simply watch the online lectures in lieu of attending class.

There is no required text. Below is a list of books that the instructors have found helpful over the years for learning (and teaching) the material in this class.

Linear algebra and function spaces:

- Strang: *Linear Algebra and its Applications* [amzn.to/2vYq6eL]
- Strang: *Computational Science and Engineering* [amzn.to/2vCexJu]
- Horn and Johnson: *Matrix Analysis* [amzn.to/2fJ9fWY]
- Young: *An Introduction to Hilbert Space* [amzn.to/2vZEx2b]

Mathematics of signal processing:

- Moon and Stirling: *Mathematical Methods and Algorithms for Signal Processing* [amzn.to/2uGMkSI]
- Vetterli et al: *Foundations of Signal Processing* [amzn.to/2vGqsnF]
- Scharf: *Statistical Signal Processing* [amzn.to/2x2px0y]

Course Expectations and Guidelines

Academic integrity

Georgia Tech aims to cultivate a community based on trust, academic integrity, and honor. Students are expected to act according to the highest ethical standards. For information on Georgia Tech's Academic Honor Code, please visit www.catalog.gatech.edu/policies/honor-code. Any student suspected of cheating or plagiarizing on a quiz, exam, or assignment will be reported to the Office of Student Integrity, who will investigate the incident and identify the appropriate penalty for violations.

Unauthorized use of any previous semester course materials, such as tests, quizzes, and homework, is prohibited in this course. Furthermore, redistributing materials from this semester (e.g., contributing to test banks, CourseHero, Chegg, or similar sites) is also prohibited.

Collaboration and group work

Students are *strongly* encouraged to discuss homework problems with one another. However, **each student must write up and turn in their own solutions written in their own words**. **Cases where solutions appear to be identical or nearly identical will be immediately referred to the Office of Student Integrity.**

Absences, late assignments, and missed exams

Attendance and active participation in the lectures is a factor in your grade. However, you will not be penalized for any excused absences (e.g., due to illnesses, religious observances, career fairs, job interviews, etc.) I plan to discuss the homework assignments in class on the day that they are due, and thus **I cannot accept late homeworks**. In the event that an excused absence prevents you from submitting an assignment, your homework grade will be calculated on a prorated basis. **If you expect to miss a quiz or exam, please contact me as soon as possible to make alternative arrangements.** We may consider options to take the quiz at an alternate time or instead may adjust the grading allocation to place more emphasis on other quizzes/exams, depending on the circumstances.

Accommodations for students with disabilities

If you are a student with learning needs that require special accommodation, contact the Office of Disability Services at (404)894-2563 or disabilityservices.gatech.edu, as soon as possible, to make an appointment to discuss your special needs and to obtain an accommodations letter. Please also e-mail me as soon as possible in order to set up a time to discuss your learning needs.

Student-Faculty expectations agreement

At Georgia Tech we believe that it is important to strive for an atmosphere of mutual respect, acknowledgement, and responsibility between faculty members and the student body. In the end, simple respect for knowledge, hard work, and cordial interactions will help build the environment we seek. Therefore, I encourage you to remain committed to the ideals of Georgia Tech while in this class. See www.catalog.gatech.edu/rules/22 for an articulation of some basic expectation that you can have of me and that I have of you.

Outline

The outline below should be treated as an approximation; it is subject to changes.

1. Signal representations in vector spaces
   (a) Discretizing signals using a basis: The Shannon-Nyquist sampling theorem
   (b) Linear vector spaces, linear independence, and basis expansions
   (c) Norms and inner products
   (d) Orthobases and the reproducing formula
   (e) Parseval's theorem and the general discretization principle
   (f) Important bases: Fourier, discrete cosine, lapped orthogonal, splines, wavelets
   (g) Signal approximation in an inner product space
   (h) Gram-Schmidt and the QR decomposition
2. Linear inverse problems
   (a) Introduction to linear inverse problems, examples
   (b) The singular value decomposition (SVD)
   (c) Least-squares solutions to inverse problems and the pseudo-inverse
   (d) Stable inversion and regularization
3. Matrix approximation using least-squares
   (a) Low-rank approximation of matrices using the SVD
   (b) Total least-squares
   (c) Principal components analysis
4. Computing the solutions to least-squares problems
   (a) Cholesky and LU decompositions
   (b) Structured matrices: Toeplitz, diagonal+low rank, banded systems
   (c) Large-scale systems: Steepest descent and the conjugate gradient method
5. Low-rank updates for streaming solutions to least-squares problems
   (a) Recursive least-squares
   (b) The Kalman filter
   (c) Adaptive filtering using LMS
6. Beyond least-squares (topics as time permits)
   (a) Approximation in non-Euclidean norms
   (b) Regularization using non-Euclidean norms
   (c) Recovering vectors from incomplete information (compressed sensing)
   (d) Recovering matrices from incomplete information (matrix completion)