ECE 3803: Optimization for Information Systems
Fall 2021 Syllabus

Summary

ECE 3803 is an introduction to the fundamentals of optimization with a focus on algorithms and applications in signal processing, control systems, machine learning, and robotics. The central theme of the course is the use of linear algebra and optimization in posing and solving practical information processing problems. Upon successful completion of this course you should be able to:

- pose real-world engineering tasks as optimization problems and recognize common kinds of optimization problems when you encounter them,
- efficiently compute the solutions to large-scale optimization problems, and
- understand how to combine data with mathematical models to solve practical engineering problems.

Lecture

Tuesdays and Thursdays from 9:30-10:45am in Van Leer C341

Instructor

Mark Davenport
Email: mdav@gatech.edu
Office hours: TBD. Additional availability by appointment.

Prerequisites

An introductory course in linear algebra and multivariable calculus (MATH 2551 or equivalent) is the main pre-requisite. Most of the course will use the language of matrices and vectors. Students should be comfortable with the use of matrices to represent systems of equations and the notion of taking a gradient of a function of many variables. Familiarity with eigenvalues, eigenvectors, and eigenvalue decompositions will be extremely helpful. Finally, students should also have basic Python programming skills (CS 1301 or equivalent).

Grading

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

- **Homeworks (40%):** There will be ≈ 10 homework assignments. See further details below.
- **Quizzes (30%):** There will be 2 quizzes. These are *tentatively* scheduled for September 21 and November 2.
- **Final exam (25%):** This will be a cumulative exam that will take place during the regularly scheduled final exam period (December 16, 8am-10:50am).
- **Participation (5%):** This is based on my assessment of your engagement in the course. This will be based on factors such as 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" quiz/exam scores as necessary (by adjusting the grades higher, but not lower) if I determine that a quiz was more difficult than I intended.

Homework

Homework will be assigned weekly (approximately). **Homework will be turned in via canvas. Unless you have made prior arrangements with me, late submissions 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** $(N-1)\cdot 100$**, where** N **is the number of assignments** – 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.)

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 and optimization play in data science, machine learning, and signal processing (among other things). Effectively, homework is worth much more than 40% of your grade. In teaching many courses over the years, **I have never seen a case where a student does not put effort into the homework assignments but does well on the exams**.

Course Materials

The course webpage is at: mdav.ece.gatech.edu/ece-3803-fall2021. This page will provide general course information, links to lecture notes/videos, 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/fall2021/ece3803/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.

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

Linear algebra

- Strang: *Linear Algebra and its Applications* [amazon]
- Trefethen and Bau: *Numerical Linear Algebra* [amazon]
- Horn and Johnson: *Matrix Analysis* [amazon]

Optimization

- Boyd and Vanderberghe: *Convex Optimization* [Available as a free pdf from author's website]
- Calafiore and El Ghaoui: *Optimization Models* [amazon]
- Nocedal and Wright: *Numerical Optimization* [amazon]
- Luenberger: *Optimization by Vector Space Methods* [amazon]

Machine learning

- Watt, Borhani, and Katsaggelos: *Machine Learning Refined* [amazon]
- Strang: *Linear Algebra and Learning from Data* [amazon]
- Hastie, Tibshirani, and Friedman: *The Elements of Statistical Learning*, [Available as a free pdf from author's website]
- Abu-Mostafa, Magdon-Ismail, and Lin: *Learning from Data.* [amazon]

Potpourri

- Domingos: *The Master Algorithm* [amazon]
- Schneier: *Data and Goliath* [amazon]
- O'Neil: *Weapons of Math Destruction* [amazon]

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.

Redistributing materials from this course and/or using external sites for assistance (e.g., contributing to test banks, CourseHero, Chegg, or similar sites) is 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 quizzes

Active participation in the class discussions is a factor in your grade. You are expected to attend these discussions unless you have a compelling reason not to do so. 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 the day after 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 pro-rated basis. **If you expect to miss a quiz, please contact me as soon as you realize this so we can 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, 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. The method of least squares
   (a) Applications and formulation: Regression and interpolation
   (b) Solving least squares problems (Review of multivariable calculus)
   (c) Understanding least squares problems (Review of linear algebra)
   (d) Computing least squares solutions
2. Unconstrained optimization
   (a) Convexity
   (b) Gradient descent
   (c) Acceleration: Conjugate gradients, the heavy ball method, Nesterov's optimal method
   (d) Newton's method and quasi-Newton methods
   (e) Non-smooth optimization
   (f) Stochastic gradient descent
   (g) Applications: Approximation, filter design, tracking, logistic regression, neural networks
3. Constrained optimization
   (a) Lagrange duality
   (b) The KKT conditions
   (c) Algorithms for constrained optimization
   (d) Linear programs
   (e) Quadratic programs
   (f) Second order cone programs
   (g) Semidefinite programs
   (h) Applications: Support vector machines, portfolio optimization, feature selection, optimal power flow, recommendation systems
4. Beyond convex optimization
   (a) Integer programming
   (b) Dynamic programming
   (c) Optimization on graphs
   (d) Optimization in game theory
   (e) Applications: Error correction, optimal control, reinforcement learning, generative adversarial networks