ORF 363/COS 323, Fall 2020

Computing and Optimization for the Physical and Social Sciences

http://aaa.princeton.edu/orf363

Course description

An introduction to several fundamental and practically-relevant areas of numerical computing with an emphasis on the role of modern optimization. Topics include convex optimization, computational linear algebra, linear and semidefinite programming, optimization for statistical regression and classification, computational complexity theory, and techniques for dealing with uncertainty and intractability in optimization problems. Extensive hands-on experience with high-level optimization software. Applications drawn from operations research, statistics and machine learning, finance, economics, and engineering.

Course website

- The course will be on Blackboard and we will have Piazza.
- Lecture notes and problem sets will also be posted here: http://aaa.princeton.edu/orf363

Class schedule

Tue, Thu 1:30 pm-2:50 pm EST. Zoom link for Lectures (password has been emailed to you).

Distribution area

Quantitative reasoning.

Certificate programs

The course counts towards the certificates in

- Applications of Computing
- Statistics and Machine Learning
- Engineering and Management Systems
- Robotics and intelligent systems

Instructor

Amir Ali Ahmadi, Professor at ORFE. Web: http://aaa.princeton.edu/
Email: aaa@p...

Co-instructor

Shen Shen, Postdoctoral Scholar and Lecturer at ORFE. Web: https://shensquared.github.io/
Email: shenshen@mit.edu

Graduate student AIs

- Abraar Chaudhry (1/2 AI)
- azc@p...

- Brian Cheung
- bcheung@p...

- Cemil Dibek (volunteer)
- cdibek@p...

- Grace Lee
- gylee @p...

- Xiaohe Luo
- xiaohel@p...

- Sobhan Miryoosefi
- miryoosefi@p...

- William Underwood
- wgu2@p...

Office hours and precepts (Zoom link for all of them; password has been emailed to you)

▪10 weekly office hours:

- **Mondays: 9-10:30am (Grace), 4:30-6pm (Sobhan), 7-8:30pm (Abraar)**
- **Tuesdays: 9-10:30am (Xiaohe), 4:30-6pm (Shen), 7-8:30pm (Brian)**
- **Wednesdays: 3-4:30pm (AAA), 4:30-6pm (Shen), 7-8:30pm (William)**
- **Thursdays: 9-10:30am (Cemil)**

▪6 weekly precepts (each with ~15 students):

- **Thursdays: 4:30-5:20pm, 6-6:50pm**
- **Friday mornings: 9-9:50am, 11-11:50am**
- **Friday afternoons: 1:30-2:20pm, 3:30-4:20pm**

Piazza

Please sign up at http://piazza.com/princeton/fall2020/orf363
A password has been emailed to you.

Prerequisites

- Multivariable Calculus: MAT201 or MAT203
- Linear Algebra: MAT202 or MAT204
- Familiarity with MATLAB

Textbooks

Recommended as reference (instructor lecture notes are the only required reference):

- *An Introduction to Optimization,* K. P. Chong & S. H. Zak, *4th ed.*
- *Algorithms,* S. Dasgupta, C. Papadimitriou, and U. Vazirani.
- *Introduction to Applied Linear Algebra – Vectors, Matrices, and Least Squares*
  https://web.stanford.edu/~boyd/vmls/
- *Linear Programming: Foundations and Extensions,* R.J. Vanderbei.
  Available for free download to Princeton students:
  http://link.springer.com/book/10.1007/978-1-4614-7630-6
- *Convex Optimization,* S.Boyd, and L. Vandenberghe.
  Available for free download:
  http://web.stanford.edu/~boyd/cvxbook/

Software

Students will use the MATLAB-based optimization software CVX (http://cvxr.com/cvx/) to solve a variety of real-world (but simplified) problems having to do with optimization and computing in operations research, machine learning, finance, economics, and engineering. Students are free to use other programming languages (e.g. CVX in Python) but the solutions that we provide will be in MATLAB.

Course grade

- 50% homework (around 8 problem sets; will drop the lowest score); almost all problem sets will involve a computational component
- 20% midterm, 2 hours in duration including submission time (100 mins exam, 20 mins submission), closed notes (except for one page of notes)
- 30% final, 48-hour take-home, open notes, involves a computational component.
- Students can choose between a letter grade and a PDF option.

Homework

Homework will be due before lecture, at 1:30 pm EST. Homework (and exams) must always be submitted as a single PDF file which includes your code. Both typed and hand-written solutions are accepted. Unless there is an *extremely valid* reason, requests for extension on homework will not be accepted. To help stick with this policy, we drop your lowest homework score.

Midterm

The midterm must be taken in a single continuous 100-min session. An additional 20 minutes are allowed for electronic submission of the exam. Midterm is closed-book and closed-notes. However, you can take a single sheet of standard-sized paper with you (double-sided) with anything you want written on it. No electronic devices are allowed; no calculators, no phones, etc. There will be no computer exercises on the midterm.

Final

There will be a take-home final exam. This will be a cumulative exam but with more focus on the second half of the course. You cannot discuss the exam with anyone other than the professor, the co-instructor, and the TAs. The date of the exam is to be announced later in the semester. The final (just like the homework) will have both a mathematical component and a computational component.

Collaboration policy

Homework: You are allowed and in fact encouraged to collaborate on the homework. You have to turn in your individual assignment and you have to write the name of the students with whom you worked with on the first page of your homework. Full credit will be given to all members of the team.

Midterm and final exam: No collaboration allowed.

Tentative list of lectures and problem sets:

- Lec1: Let's play two games! (Optimization, P and NP.)
- Lec2: What you should remember from linear algebra and multivariate calculus.
- HW1: Brush up on linear algebra, multivariate calculus, and MATLAB.
- Lec3: Unconstrained optimization, least squares, optimality conditions.
- Lec4: Convex optimization I.
- HW2: Image compression and SVD, optimality conditions, convex sets.
- Lec5: Convex optimization II.

- Lec6: Applications in statistics and machine learning: LASSO+SVMs.
- HW3: Convex analysis and convex optimization.
- Lec7: Root finding and line search: bisection, Newton, and the secant method.
- Lec8: Gradient descent methods, analysis of steepest descent, rates of convergence.
- HW4: Support vector machines.
- Lec9: Quadratic convergence of Newton's method, nonlinear least squares and Gauss-Newton.
- Lec10: Conjuagate direction methods, solving linear systems, Leontief economy.
- HW5: New gym and movie theater for Princeton + Newton fractals.
- Lec11: Linear programming: applications, geometry, and the simplex algorithm.
- Lec12: Duality and robust linear programming.
- HW6: Leontief economy + conjuagate gradients + radiation treatment planning.
- Lec13: Semidefinite programming, SDP relaxations for nonconvex optimization.
- Lec14: A working knowledge of computational complexity for an optimizer.
- HW7: Optimal control + linear programming.
- Lec15: William Pierson Field Lecture by Sanjeeb Dash: Optimization at IBM Research.
- Lec16: Limits of computation, course recap.
- HW8: End-of-semester party at AAA's + Doodle and scheduling + SDP + NP-completeness.

Participation & comments on Zoom and Piazza

Our lectures will be recorded and posted on Blackboard. Office hours and precepts will not be recorded so students feel more comfortable asking questions. (We have tried to schedule multiple office hours and precepts to accommodate different time zones.) Although no grade is assigned to participation, we strongly encourage you to ask questions on Zoom during lectures, office hours, and precepts. This can help us have a more interactive experience. If you feel comfortable, please share your video on Zoom (you can select a virtual background if you prefer). We also encourage you to take advantage of Piazza to initiate mathematical discussions with your teaching staff and classmates.

Honor code

We strictly adhere to Princeton University’s Undergraduate Honor System.