ChE/EID488: Convex Optimization Techniques

Prof. Davis

Spring 2022 Syllabus

Class meeting times:

Tuesdays 10 – 11:50 AM in room 106 or on MS Teams
Thursdays 11 – 11:50 AM in room 106 or on MS Teams

Prerequisites and other requirements:

The prerequisites for this class are MA326 (Linear Algebra) and any of ChE352 (Process Simulation and Mathematical Techniques for Chemical Engineers), ESC161 (Systems Engineering), or ESC110 (MATLAB Seminar: Signals and Systems). **You must have a strong background in mathematics** and be comfortable coding in Matlab or Python. This class will be slightly more fundamental than a typical graduate-level class in linear and nonlinear programming; students should expect to use their knowledge of analysis, linear algebra, and geometry. The course has a required textbook: An Introduction to Optimization by Chong and Zak (4^{th} ed.) ISBN# 1118279018. I will generally be following the textbook through the course; you should purchase it and **bring your copy with you to class**.

Course overview:

This course discusses methods for setting up and solving optimization problems of engineering and economic interest using the techniques of unconstrained, linear, and nonlinear programming. One eventual goal of the course is to give you enough context to understand convex optimization, which is the solution of problems with only global minima or maxima (one optimal value). The course is centered around a project, where students pose, set up, and solve a problem of their choice. We will consider example problems across engineering disciplines such as network flow, portfolio optimization, transportation, etc. The focus will be on theory and problem formulation, with some computational components. The first half will cover:

- Introduction to optimization and motivating problems
- Methods of proof and notation (Ch. 1)
- Matrices, Matrix properties, Norms (Ch. 2 and 3)
- Geometry of typical sets from optimization problems (Ch. 4)
- Review of multivariable calculus (Ch. 5)
- Unconstrained optimization (Ch. 6)
- Algorithms and solution methods for unconstrained problems (Ch. 7-11)

The second half of the course will cover:

- Linear programming problems (Ch. 15)
- Solution methods for linear and integer programming problems (Ch. 16 and Ch. 19)
- Duality in LPs and examples of linear programs (Ch. 17)
- Nonlinear constrained programming problems and their optimality conditions (Ch. 20-21)
- Convexity and convex optimization problems (Ch. 22)
- Global search methods and basics of neural networks (Ch. 12-14)

Course goals and objectives:

By the end of this course, you should be able to:

- Create your own optimization problems from a physical situation
- Transform problems into equivalent forms by changing or removing variables, modifying the objective, removing inactive constraints, etc.
- List and evaluate optimality conditions for unconstrained, linear, and various types of convex problems
- Find the dual of a problem and identify its relation to the primal
- Use at least one method to solve a convex programming problem using a computer
- Identify problems as unconstrained, linear, integer, nonlinear, convex, quadratic, mixed integer nonlinear, etc.
- Explain why posing a problem in a convex form is generally better than an alternative non-convex form

Homework Assignments and Exams:

You will be given five (5) homework assignments (HWs), a project assignment, and one midterm exam. The HWs will be due before class on the date listed in the schedule below (unless otherwise stated on the assignment) and will be assigned at least one week prior to their due date. HWs will consist of problems and essay questions which reinforce concepts from class and the text. Some assignments will take longer to complete than others, though I will do as much as I can to minimize this. This is a 3 credit class, so I expect that you will spend 6 hours per week outside of class on work for this class. The project will be done in groups of 1-2 and will be assigned on the first day of class.

Groups:

You will be assigned a group at multiple points in this class. You will work together as a group on all HWs (and possibly the project) and be graded together on those assignments. Groups will be assigned by me on the second day of class. After HW2 has been submitted by each group, groups will be reassigned by me for HW3 and HW4. You may choose your own group (subject to my approval of your group) for the project and HW5. I reserve the right to reassign groups at any time without consent of any members of that group based on the following criteria: performance on HWs (either too low or too high), well-founded complaints by any member of the group, or the need to split up another group (and thus break up two groups to form two new groups).

The HWs will be done in groups of 2-3 but each group member must submit THEIR OWN work. Only one of the 2-3 assignments (chosen randomly by me) will be graded. The grade on that submission AND ONLY THAT SUBMISSION will be given to all group members. It is the responsibility of each group member to ensure that all assignments are of similar quality. Only one project submission (Project Proposal, First Draft, and Final Report) is required per group.

You are REQUIRED to put the names of ALL members of your group on your submissions. If any names do not appear, I reserve the right to give a zero grade to any person whose name does not appear at my discretion. You are also REQUIRED to submit a group member evaluation form for each group member you work with during the semester. The evaluation form will be available on MS Teams.

Attendance and Grading Policy:

Attendance in class is mandatory. Please E-mail me before class if you cannot attend. If you miss class, please come to my office hours to find out what you missed. In-class activities are also mandatory; they are an important part of learning the material and attempting them is essential to the course. There will be no make-up or extra credit work associated with this class. Please ensure that you hand in your assignments on time; all assignments must be completed for a passing grade in the class.

Students will be graded as follows:

	Homework	**Midterm Exam**	**Project**
% of grade	25	30	45

Letter grades will be determined at the end of the semester using each student's raw score from above, the average raw score for the class, and my discretion (in that order). My discretion will be based on class attendance / participation, effort on homework assignments, and improvement over the course of the semester.

Group Work and Academic Integrity Policy:

I believe group work is important to learning; I am requiring you to work in groups of 2-3 on your homework assignments and you may work in groups of 2 on your project. However, each student MUST submit their own work for each HW and contribute as equally as possible to the project. I will choose randomly each week which group member's homework submission I will grade. This means that you must work closely with your group members to ensure that you are all doing the work and that you are doing it correctly.

Plagiarism is the presentation of another person's "work product" (ideas, words, equations, computer code, etc.) as one's own. Whether done intentionally or unintentionally, plagiarism will not be tolerated in this class. You are plagiarizing if:

1. You present as your own work product a submission that includes the work product of your other group members
2. You present as your own work product a submission that contains the efforts or work product of other individuals aside from your other group members
3. The help and contributions of other individuals are not acknowledged in writing on your submission (by writing their names)
4. You copy the work of other students on an in-class examination or communicate with other individuals in any fashion during an exam
5. You submit as part of a homework assignment or project material that has been copied from any source (including, but not limited to, a textbook, a periodical, an encyclopedia, the internet) without properly citing the source, and/or without using quotation marks. It is also prohibited to submit such materials in a minimally altered form without proper attribution. Improperly copied material might include text, graphics (computer or otherwise), computer source code, etc.

The engineering school policy on academic integrity is linked here. Other prohibited acts of academic dishonesty include (but are not limited to):

6. Resubmitting work completed (even if by you) for another class at Cooper or elsewhere
7. Attempting to obtain a copy of an examination before it is administered
8. Dishonesty in dealing with me or another professor, such as misrepresenting the statements of another professor
9. Bringing a text or study materials of any kind (including electronically) into an exam when forbidden to do so
10. Bringing any device to class, electronic or otherwise, not expressly permitted by me
11. Bringing any device into an examination that allows communication with other individuals, computers or the internet (i.e. no cell phones or laptops during exams)

Resources which may be helpful for the class and/or for the project:

http://www.engr.colostate.edu/~echong/book4/ – Website for Chong and Zak textbook
Convex Optimization by L. Vandenberghe and S. Boyd (1st ed.) ISBN# 0521833787 (EE)
Linear and Nonlinear Programming by D. Luenberger (2nd ed.) ISBN# 1402075936 (Management / Economics)
Introduction to Optimization by Pablo Pedregal (1st ed.) ISBN# 0387403981 (Math)
Principles of Optimal Design: Modeling and Computation by P. Papalambros and D. Wilde (2nd ed.) ISBN# 0521627273 (MechE)
http://www.optimaldesign.org/ – Website for Papalambros and Wilde textbook
Introduction to Applied Optimization by U. Diwekar (2nd ed.) ISBN# 9780387766348 (ChemE)
Optimization of Chemical Processes by T. Edgar and D. Himmelblau (2nd ed.) ISBN# 0071189777 (ChemE)
http://www.mathworks.com/products/optimization/index.html – Optimization toolbox in Matlab (useful for learning about algorithms for solving problems in this class in Matlab)
https://docs.scipy.org/doc/scipy/reference/optimize.html - Optimization and root finding functions in Python

Office hours:

Mondays 12:00 – 1:00 PM, Tuesdays 4:30 – 5:30 PM, Fridays 1:00 – 2:00 PM
Please do your best to bring questions to me during those times only. My E-mail address is ben.davis@cooper.edu if you have a question which is brief or if you need to let me know you're going to be absent, late, etc. If you send me an E-mail, please put "ChE488" or "EID488" as the start of the subject, e.g. "EID488: HW1 Question".

Sequence of topics and class schedule:

Below is a rough outline of the order of topics I plan to cover in class. Assignment due dates are on the right. Each group must submit a project proposal, a first draft, and a final draft. Remote days are in red.

Week	Hour#	Day	Date	Topic(s)	Due
1	1	Thu	1/20	Syllabus and Introduction to Course	
2	2,3	Tue	1/25	Ch. 1 and 2 (methods of proof, notation)	
2	4	Thu	1/27	Ch.2 (Matrix Properties, Linear Systems)	
3	5,6	Tue	2/1	Example Problems, Chapter 3	HW1
3	7	Thu	2/3	Matrix Norms, Special Matrices, Chapter 4	
4	8,9	Tue	2/8	Ch. 4 (Sets, Geometry)	
4	10	Thu	2/10	Example problems, Chapter 5	HW2
5	11,12	Tue	2/15	Optimal Workshop Problem, ∇, ∇^2	
5	13	Thu	2/17	Hessian, Flash Problem, Chapter 6	
6	14,15	Tue	2/22	Existence of x^*	
6	16	Thu	2/24	Ch. 6 (FONC, SONC)	HW3
7	17,18	Tue	3/1	Optimal Tank Size Problem	
7	X	Thu	3/3	MT Exam Review Session	Proj. Prop.
8	X	Tue	3/8	MT Exam (THREE HOURS)	MT Exam
8	19	Thu	3/10	Chapters 7-9 (1D search, Steepest Descent, Newton's Method)	
9	X	Tue	3/15	**NO CLASS** – Spring Break	
9	X	Thu	3/17	**NO CLASS** – Spring Break	
10	20,21	Tue	3/22	Chapters 10-11 (Conjugate Gradient Methods, Quasi-Newton Methods)	Return MT
10	22	Thu	3/24	Ch. 15 (Linear Programming)	
11	23,24	Tue	3/29	Standard Form, Reforming LPs, Simplex	
11	25	Thu	3/31	More LPs, Chapter 17 (Duality in LPs)	HW4
12	26,27	Tue	4/5	Chapter 19 (Integer Programming, MILPs, Branch and Bound)	
12	28	Thu	4/7	Chapter 20 (General Nonlinear Constrained Problems)	First Draft
13	29,30	Tue	4/12	FONC and SONC for general problems	
13	31	Thu	4/14	Biggest Box Problem, PD QP Solution	
14	32,33	Tue	4/19	Ch. 21 (The KKT Conditions)	
14	34	Thu	4/21	Ch. 21 (The KKT Conditions)	HW5
15	35,36	Tue	4/26	Convex Optimization Problems	
15	37	Thu	4/28	Convex Problems, Compressor Problem	
16	38,39	Tue	5/3	Chapter 12 (Least Squares, $Ax = b$)	
16	X	Thu	5/5	**NO CLASS** – Study period	
17	40,41	Tue	5/10	Chapters 13-14 (Global Search Methods)	
17	X	Thu	5/12	**Project due electronically by 11:59 PM**	Final Report
18	X	Tue	5/17	**NO CLASS** – Grades due 5/16	