ChE / EID 488: Convex Optimization Techniques

Prof. Davis

Fall 2016 Syllabus

Class meeting times:

Tuesdays 10 – 11:50 AM in room 106
Thursdays 11 – 11:50 AM in room 106

Prerequisites and other requirements:

The prerequisites for this class are MA326 (Linear Algebra) and either ChE151 (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 linear algebra and be comfortable coding in Matlab. This class will be slightly more fundamental than a typical graduate-level class in linear and nonlinear programming.

The course has a required textbook: An Introduction to Optimization by Chong and Zak (4^{th} ed.) ISBN# 1118279018, $59 (new) @ Amazon.com. I will generally be following the textbook through the course; you should purchase it and **bring your copy with you to class**. You will need materials to take notes and do problems during class (paper, pencil, two different colors of pen, a straight edge, and a calculator) and access to a computer to do certain homework problems.

Course overview:

This course discusses in detail the methods for setting up and solving optimization problems of engineering and economic interest using the techniques of unconstrained, linear, and nonlinear programming. An eventual goal of the course is to give students enough context to understand convex optimization, which is the solution of problems with only global minima or maxima (one answer). The course is centered around a project assignment, where students will pose, set up, and solve a problem of their choice. We will consider example problems (supply chain management, network flow, portfolio optimization, etc.) across engineering disciplines. The focus will be on theory and problem formulation, with some computational component. The first half of the course (before the Midterm Exam) 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)

The second half of the course (from the Midterm to the Final Exam) will cover:

- Algorithms and solution methods for unconstrained problems (Ch. 7-14)
- 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)

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, a midterm exam, and a final 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. Homework assignments 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 one month prior to its first due date.

The Midterm Exam will be on the material I cover in class from the textbook (Chapters 1-6) and also any other introductory material and example problems I present in class. The Final Exam will generally cover the parts of chapters 7-22 of the textbook I focus on, optimization problems which I present in class, and will also include questions on the lesser understood topics covered on the Midterm Exam. The portion of the exam corresponding to each topic will be approximately equal to the amount of time spent in class on each topic. Both exams will be three hours long; the midterm will use one hour before class time and the final exam will be in its assigned slot in December.

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 third 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 to work with (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 the assignments or the Midterm Exam (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 to print out on Moodle.

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 assignments 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 and that you can attend both exams. All assignments and exams must be completed for a passing grade in the class.

Students will be graded as follows:

	Homework	**Project**	**Midterm Exam**	**Final Exam**
% of grade	20	35	25	20

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.

If I have a strong suspicion that you have plagiarized your submission for an assignment (homework or project,) you will receive a zero on that assignment. If you commit another act of plagiarism during the course after this first act, I will refer the matter to the Dean's office. Other prohibited acts of academic dishonesty include (but are not limited to):

6. Resubmitting work that has been 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, electronic or otherwise, into class at any time when not expressly permitted by me
11. Bringing any device into an examination that allows communication with other individuals or computers or computer databases (i.e. no cell phones or laptops during exams)

If I have a strong suspicion that you have cheated on an examination, you will receive a zero on that examination and likely receive a D or F in the course. The above was modified from the course catalog from the 2009-10 academic year.

Resources which may (or may not) be helpful:

http://www.engr.colostate.edu/~echong/book3/ – 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)

Office hours:

Tuesdays	2 – 3 PM in room 419
Wednesdays	4 – 5 PM in room 419
Thursdays	1 – 2 PM in room 419

Please do your best to bring questions to me during those times only. My E-mail address is bdavis@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 "ChE 488" as the start of the subject, e.g. "ChE 488: 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 (Thursdays). You must submit a project proposal, a first draft, and a final draft.

Week	Hour#	Day	Date	Topic(s)	Due
1	1,2	Tue	9/6	Syllabus and Introduction to Course	
1	3	Thu	9/8	Chapters 1 and 2	
2	4,5	Tue	9/13	Ch.2 (Matrix Properties, Linear Systems)	
2	6	Thu	9/15	Example Problems, Chapter 3	
3	7,8	Tue	9/20	Matrix Norms, Special Matrices, Chapter 4	
3	9	Thu	9/22	Ch. 4 (Sets, Geometry)	HW1
4	10,11	Tue	9/27	Example problems, Chapter 5	
4	12	Thu	9/29	Optimal Workshop Problem, ∇, ∇^2	HW2
5	13,14	Tue	10/4	Hessian, Flash Problem, Chapter 6	
5	15	Thu	10/6	Existence of x^*	HW3
6	16,17	Tue	10/11	Ch. 6 (FONC, SONC)	
6	18	Thu	10/13	Review for Midterm Exam	
7	--	Tue	10/18	Midterm Exam (in class, 9 AM – 12 PM)	
7	19	Thu	10/20	Optimal Tank Size Problem	Project Prop.
8	20,21	Tue	10/25	Chapters 7-9 (1D search, Steepest Descent, Newton's Method)	
8	22	Thu	10/27	Chapters 10-11 (Conjugate Gradient Methods, Quasi-Newton Methods)	
9	23,24	Tue	11/1	Chapters 12-14 (Least Squares, Neural Networks, Global Search Methods)	
9	25	Thu	11/3	Ch. 15 (Linear Programming, Standard Form, Reforming LPs, Simplex)	
10	26,27	Tue	11/8	More LPs, Chapter 17 (Duality in LPs)	
10	28	Thu	11/10	Duality, Chapter 19 (Integer Programming, MILPs, Branch and Bound)	HW4
11	--	Tue	11/15	NO CLASS – AIChE Annual Meeting	
11	--	Thu	11/17	NO CLASS – AIChE Annual Meeting	First Draft
12	29	Tue	11/22	Chapter 19 (General Nonlinear Constrained Problems)	
12	--	Thu	11/24	NO CLASS – Thanksgiving	
13	30,31	Tue	11/29	FONC and SONC for general problems	
13	32	Thu	12/1	Biggest Box Problem, PD QP Solution	
14	33,34	Tue	12/6	KKT Conditions	
14	35	Thu	12/8	Convex Problems, Compressor Staging Problem	HW5
15	36,37	Tue	12/13	Review for Final Exam	
15	--	???	???	Final Examination	
16	--	Wed	12/21	Project due electronically at 11:59 PM	Final Report