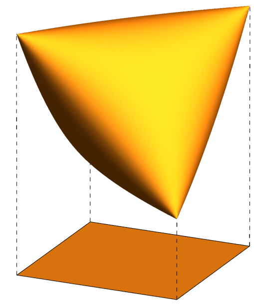
Semidefinite and Sum-of-squares Optimization (Fall 2026)



When: Tuesdays & Thursdays 12:30 PM - 01:50 PM
Where: Jacobs Hall (EBU1) Room 2315
Instructor: Yang Zheng (zhengy@ucsd.edu)
Course website: https://zhengy09.github.io/ECE285/ece285.html
Who: Graduate students (all disciplines) with an interest in convex, semidefinite, and polynomial optimization.

Course description

Convex optimization has profound impacts on many problems in control theory, discrete and nonlinear optimization, theoretical computer science, and machine learning. It is a fundamental tool to ensure efficient, resilient, and safe operations of many engineering systems, such as smart power grids, transportation, robotics, and many others. Optimization in these areas often takes the form of conic optimization, especially semidefinite programs. This course will cover semidefinite optimization, which is a far-reaching generalization of linear programs. Another emphasis of the course will be on sum-of-squares optimization that deals with optimization problems involving polynomials. Some classical applications in control and recent ones in machine learning will be covered too.

A tentative list of topics that we will cover includes

- From linear programming to conic programming; Duality theory.
- Semidefinite optimization and convex relaxations.
- Sum-of-squares and moment problems.
- Applications in control, dynamical systems, and machine learning.

Prerequisites This course assumes basic knowledge in linear algebra. Some knowledge of convex optimization will be useful. Mathematical maturity and familiarity with MATLAB, Python, or similar software are also expected.

Reading material and textbooks

I will follow my weekly notes, which will be provided on Canvas (as well as the course website). For additional reading material, I recommend:

1. Blekherman, G., Parrilo, P. A., & Thomas, R. R. (Eds.). (2012). Semidefinite optimization and convex algebraic geometry. Society for Industrial and Applied Mathematics.
2. Boyd, S., & Vandenberghe, L. (2004). Convex optimization. Cambridge University Press.
3. Lasserre, J. B. (2009). Moments, positive polynomials and their applications. World Scientific.
4. Laurent, M. & Vallentin, F. (2016) Semidefinite optimization, Lecture notes
5. Ben-Tal, A., & Nemirovski, A. (2001). Lectures on modern convex optimization: analysis, algorithms, and engineering applications. Society for industrial and applied mathematics.

Tentative Schedule

The following is a tentative schedule. I may change it as the course progresses.

Week	Date	Lecture	Assignments
0	Sep 24	L1: Introduction & course logistics	
1	Sep 29	L2: Mathematical background	Homework 1
	Oct 01	L3: Review of convexity (I)	
2	Oct 06	L4: Review of convexity (II)	
	Oct 08	L5: Conic programming	Homework 2
3	Oct 13	L6: LP, QP, QCQP, SOCP, SDP	
	Oct 15	L7: Duality in conic programming (I)	
4	Oct 20	L8: Duality in conic programming (II)	Homework 3
	Oct 22	L9: Applications of SDPs in control	
5	Oct 27	L10: Applications of SDPs in combinatorial problems	**Proposal due**
	Oct 29	L11: Nonconvex quadratic optimization and SDP relaxations	Homework 4
6	Nov 03	L12: Review	
	Nov 05	L13: Nonnegative polynomials, SOS, and SDP (I)	
7	Nov 10	L14: Nonnegative polynomials, SOS, and SDP (II)	Homework 5
	Nov 12	**Midterm exam**	
8	Nov 17	L15: SOS applications in control & machine learning	
	Nov 19	L16: Dual side: moment problems	Homework 6
9	Nov 24	L17: Nonsmooth optimization	
	Nov 26	**Thanksgiving holiday – no class**	
10	Dec 01	L18: Project presentation (tentative)	
	Dec 03	L19: Project presentation (tentative)	
11			**Project report due**

Course grading

Your grade will be assigned roughly according to the following percentages.

- 25% Homework (6 problem sets; will drop the lowest score)‡
- 35% Midterm exam (in class; one page of cheat sheet allowed)‡
- 40% Final project

‡ Recent AI tools have become powerful and may be able to solve all homework problems in this course. However, the homework is carefully designed to develop genuine understanding of the material. Homework credit will count toward the course grade only if the midterm score is above 60%. Otherwise, the midterm score will be used for both the midterm and homework components.

It is easy, and of little value, to appear knowledgeable. It is much harder, and far more valuable, to understand a topic precisely and communicate that understanding clearly. Working carefully through the homework problems is an essential part of developing this understanding.

Some additional notes:

- Partial credit may be given whenever the overall performance of each assignment is low. If answers do not have satisfactory explanations (e.g., all intermediate steps, clearly readable handwriting), we will give no credit.

- Exams will be closed book and closed notes. For the midterm exam, you may prepare one double-sided cheat sheet (letter size, 8.5 × 11 in.) in **your own handwriting**. You may write it on paper or by hand on a tablet and print it. If you use a tablet, screenshots of course materials are not allowed. Everything on your cheat sheet must be handwritten by you. No digital devices (cellphones, tablets, smart glasses, calculators, etc.) are allowed during the exam.
- We will use the normal grading scale (A+ $\geq$ 97; A $\geq$ 93; A- $\geq$ 90, etc). Final grades may be curved at my discretion to align the grade distribution with the expected performance standards for the course.

  If a curve is applied, it will be used to only benefit students and will never lower a student's grade.

Homework submission and late policy

Homework is submitted via Gradescope. The due date of each homework and project assignment will be clearly stated. We expect you to turn in all completed problem sets on time.

- Homework solutions may be typeset in LaTeX or handwritten. Handwritten solutions must be clearly legible. The project proposal and final report must follow the provided template.
- Late homework will not be accepted without prior approval. Your first three requests will be approved automatically, provided that you email the instructor (zhengy@ucsd.edu) by 11:59 pm on the day before the assignment is due.
- Your first approved late homework submission will not incur a penalty. Your second and all subsequent late homework submissions will automatically incur a 20% grade penalty, even with prior approval. No late homework will be accepted after two calendar days after the original due date.
- If you have concerns or clarification requests about a grade you received, you must submit a regrade request within one week of the grade being released.
- Regrade requests for homework or the midterm exam will not be considered during or after final exam week.

How homework assignments are graded. We will grade a representative subset (about 50%) of problems on each assignment. The subset will be selected before grading and will be the same for all students. Ungraded problems are for practice only, which will help your understanding of the course materials. You are expected to attempt all problems; any problem may be selected for grading. The graded subset will be identified when scores are returned.

AI usage policy

Generative AI tools (such as ChatGPT and Claude etc.) are becoming more widely available and can be valuable resources when used thoughtfully and responsibly. In this course, you are permitted to use generative AI tools to brainstorm ideas, clarify complex concepts, organize your thoughts, and check grammar of your writing. However, you must write your own solutions in the end. It is academically dishonest and unacceptable to submit any work generated by an AI as your own.

The core principle is that **the work you submit must reflect your own understanding and intellectual effort**.

- You should be able to explain the reasoning behind every step of your submitted work.

- If you use an AI tool for assistance in any assignment, I would appreciate a brief statement at the end of your work clarifying which tool you used and for what specific purpose.
- Submitting AI-generated content without proper attribution or presenting it as your own original work constitutes a violation of academic integrity.
- You are responsible for the factual accuracy and originality of everything you submit. If you are unsure whether a particular use is acceptable, please ask before submitting your work.

Course project

Each project should consist of two team members (in exceptional cases, we may allow individual projects, but please talk with the instructor to get an approval first). For each assignment, please briefly describe the role of each member. Both team members will receive the same grade.

The goal of the course project is to develop a deeper understanding of a particular topic in semidefinite optimization, polynomial optimization, or convex optimization more generally. The emphasis is on careful reading, clear explanations, and numerical exploration. You are expected to understand the main ideas and technical details of your chosen topic, but you are not required to produce new research results.

- **Option 1: Literature review and numerical reproduction**: prepare a detailed review of 2 (or 3) closely related papers on a particular topic (You may read additional relevant papers as needed, but you are not expected to review them in depth). Explain the problem being studied, the main ideas and results, and the connections and differences among the papers. In addition, reproduce representative numerical results from one of the papers by implementing the relevant algorithms and testing them on selected problem instances. Explain your implementation and discuss how your results compare with those reported in the paper.
- **Option 2: Literature review and exploratory extension**: Start with a review of 2 (or 3) closely related papers, then explore a question motivated by your reading or your own research. For example, you might investigate a variant of an existing method, examine the role of an assumption, or apply a method to a different problem. Explain the motivation for your exploration and support your observations with mathematical analysis or numerical experiments. New theoretical results or improved performance are welcome but are not required. The emphasis is on asking a meaningful question, investigating it carefully, and explaining what you learned.

AI policy. The course AI policy also applies to the project. All project assignments, including the proposal (5%), presentation (20%), and final report (20%), must be completed by the team members and reflect your own understanding and intellectual effort. Each team member is expected to develop a thorough understanding of the project and be able to explain its main ideas and technical details.

Check the course website for further details.

Collaboration and Academic Integrity

UCSD's Code of Academic Integrity applies to this course. It is dishonest to cheat on exams, copy other people's work, or fake experimental results. An important element of academic integrity is fully and correctly acknowledging any materials taken from the work of others.

Collaboration policy: We encourage working together whenever possible: homework sets, lecture notes, general discussions of projects. But please note that the work you turn in should be your own! It is not acceptable to copy a solution that someone else has written. Instances of academic dishonesty will be referred to the Office of Student Conduct for adjudication.

Acknowledgments

The initial development of this course was inspired by the following courses:

- Topics in Convex Optimisation, University of Cambridge (Lecturer: Hamza Fawzi)
- ORF523: Convex and Conic Optimization, Princeton University (Lecturer: Amir Ali Ahmadi)
- 6.256 Semidefinite Optimization, MIT (Lecturer: Pablo A. Parrilo)