Course Syllabus

ISYE 6669

Deterministic Optimization

Fall 2022

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Course Description

The course will teach basic concepts, models, and algorithms in linear optimization, integer optimization, and convex optimization. The first module of the course is a general overview of key concepts in optimization and associated mathematical background. The second module of the course is on linear optimization, covering modeling techniques, basic polyhedral theory, simplex method, and duality theory. The third module is on nonlinear optimization and convex conic optimization, which is a significant generalization of linear optimization. The fourth and final module is on integer optimization, which augments the previously covered optimization models with the flexibility of integer decision variables. The course blends optimization theory and computation with various applications to modern data analytics.

Prerequisite

- Linear algebra
- Multivariate Calculus
- Basic Probability
- Familiarity with programming in Python

Course Goals

Student who take this course can expect to achieve the following goals:

- Learn modeling skills for formulating various analytics problems as linear, convex nonlinear, and integer optimization problems
- Learn basic optimization theory including duality theory and convexity theory, which will give the students a deeper understanding of not only how to formulate an optimization model, but also why.

- Learn fundamental algorithmic schemes for solving linear, nonlinear, and integer optimization problems.
- Learn computational skills for implementing and solving an optimization problem using modern optimization modeling language and solvers.

Grading Policy

- There will be one midterm quiz and one final quiz that will be graded by faculty. The midterm will be 35% and the final will be 40% of the overall grade.
- There will be homework assignments most weeks of the semester. Your two lowest homework grades will be dropped, and the remaining ones will add up to 25% of the course grade. Some of the assignments will be faculty graded, and others will be peer-graded (based on the median score assigned by your peer graders). You will also need to peer-grade others' homework; you will not receive a final grade for your homework submission if you do not complete your peer assessments.
- For OMS Analytics degree students, quizzes will be scaled to letter grades based on their difficulty and combined with the homework to determine an overall letter grade scale at the end of the semester.
- Grade Breakdown

Homework	25%
Midterm	35%
Final Exam	40%
Total	100%

Homework and Quizzes Due Dates

All homework and quizzes will be due at the times in the table at the end of this syllabus. These times are subject to change so please check back often. Please convert from EST to your local time zone using a Time Zone Converter.

Timing Policy

- The Modules follow a logical sequence
- Assignments should be completed by their due dates.
- Quizzes must be completed during the time allotted on the schedule.
- You will have access to the course content for the scheduled duration of the course.

Quiz Policy

- No notes (apart from what is stated bellow), books, or calculator/computers are allowed in the midterm and final quizzes.
- For midterm and final quizzes, you are allowed two blank sheets of paper for scratch work (OMS Analytics degree students will be proctored; you will have to show the front and back of the blank sheet while you are being proctored). For midterm you are allowed to use one sheet of paper with notes. For final you are allowed two sheets of paper with notes. Each student must prepare their own notes.

Attendance Policy

- This is a fully online course.
- Login on a regular basis to complete your work, so that you do not have to spend a lot of time reviewing and refreshing yourself regarding the content.

Plagiarism Policy

- Plagiarism is considered a serious offense. You are not allowed to copy and paste or submit materials created or published by others, as if you created the materials. All materials submitted and posted must be your own.

Student Honor Code

All OMS Analytics degree students should abide by the Georgia Tech Student Honor Code

- Review the Georgia Tech Student Honor Code: www.honor.gatech.edu.
- Any OMS Analytics degree student suspected of behavior in violation of the Georgia Tech Honor Code will be referred to Georgia Tech's Office of Student Integrity.

Communication

- All learners should ask questions, and answer their fellow learners' questions, on the course discussion forums. Often, discussions with fellow learners are the sources of key pieces of learning.
- OMS Analytics degree students can also ask questions of the instructor and teaching assistants via Piazza.

Netiquette

- Netiquette refers to etiquette that is used when communicating on the Internet. Review the Core Rules of Netiquette. When you are communicating via email, discussion forums or synchronously (real-time), please use correct spelling, punctuation and grammar consistent with the academic environment and scholarship[1].
- In Georgia Tech's MS in Analytics program, we expect all participants (learners, faculty, teaching assistants, staff) to interact respectfully. Learners who do not adhere to this guideline may be removed from the course.

  [1]Conner, P. (2006-2014). Ground Rules for Online Discussions, Retrieved 4/21/2014 from https://tilt.colostate.edu/teachingResources/tips/tip.cfm?tipid=128

Course Topics and Sample Pacing Schedule

- The table below contains a course topic outline and homework due dates.

Weeks	Course Topics	Release Dates
Week 1	Module 1: Introduction • Lesson 1: Introduction to Optimization Models • Lesson 2: Mathematical ingredients • Lesson 3: Classification of optimization problems Module 2: Illustration of the optimization process ○ Lesson 1: A portfolio optimization problem ○ Lesson 2: Formulating a portfolio optimization model ○ Lesson 3: Solving the portfolio optimization model ○ Lesson 4: Summary of the optimization process	Aug 22, 2022 at 8: 00 a.m. Eastern
Week 1 Homework	Homework 1	Aug 22 at 8: 00 a.m. Eastern – Sept 1 at 11:59 p.m.

		Peer Assmt: Sept 1 at 11:59 Eastern – Sept 5 at 11:59 Eastern
Week 2	Module 3: Review of Mathematical Concepts • Lesson 1: Linear Algebra • Lesson 2: Properties of Functions • Lesson 3: Properties of Sets Module 4: Convexity • Lesson 1: Convex Functions • Lesson 2: Convex Sets • Lesson 3: Convex Optimization Problems	Aug 29, 2022 at 8: 00 a.m. Eastern
Week 2 Homework	Homework 2	Aug 29 at 8: 00 a.m. Eastern – Sept 8 at 11:59 p.m. Peer Assmt: Sept 8 at 11:59 Eastern – Sept 12 at 11:59 Eastern
Week 3	Module 5: Outcomes of Optimization • Lesson 1: Possible Outcomes of Optimization • Lesson 2: Existence of Optimal Solutions • Lesson 3: Local and Global Optimal Solutions • Lesson 4: Idea of Improving Search Module 6: Optimality Certificates • Lesson 1: Optimality Certificates and Relaxations • Lesson 2: Lagrangian Relaxation and Duality	Sept 5, 2022 at at 8: 00 a.m. Eastern
Week 3 Homework	Homework 3	Sept 5 at 8: 00 a.m. Eastern – Sept 15 at 11:59 p.m. Peer Assmt: Sept 15 at 11:59 Eastern – Sept 19 at 11:59 Eastern

Week 4	Module 7: Unconstrained Optimization: Derivative Based • Lesson 1: Optimality Conditions • Lesson 2: Gradient Descent • Lesson 3: Newton's Method Module 8: Unconstrained Optimization: Derivative Free • Lesson 1: Methods for Univariate Functions • Lesson 2: Methods for Multivariate Function	Sept 12, 2022 at 8: 00 a.m. Eastern
Week 4 Homework	Homework 4	Sept 12 at 8: 00 a.m. Eastern – Sept 22 at 11:59 p.m. Peer Assmt: Sept 22 at 11:59 Eastern – Sept 26 at 11:59 Eastern
Week 5	Module 9: Linear Optimization Modeling - Network Flow Problems • Lesson 1: Introduction to LP Modeling • Lesson 2: Optimal Transportation Problem • Lesson 3: Maximum Flow Problem • Lesson 4: Shortest Path Problem Module 10: Linear Optimization Modeling - Electricity Market • Lesson 1: How Electricity Markets Work • Lesson 2: Modeling Power plant Scheduling Using LP • Lesson 3: Market Clearing Mechanism • Lesson 4: A Real-World Example	Sept 19, 2022 at 8: 00 a.m. Eastern
Week 5 Homework	Homework 5	Sept 19 at 8: 00 a.m. Eastern – Sept 29 at 11:59 p.m.

		Peer Assmt: Sept 29 at 11:59 Eastern – Oct 3 at 11:59 Eastern
Week 6	Module 11: Linear Optimization Modeling - Decision-Making Under Uncertainty • Lesson 1: the Need to Make Decisions Under Uncertainty • Lesson 2: Two-Stage Stochastic Linear Programming • Lesson 3: An Example Using Stochastic LP • Lesson 4: How to Solve Stochastic Programs Module 12: Linear Optimization Modeling - Handling Nonlinearity • Lesson 1: The Power of Piecewise Linear Functions • Lesson 2: Robust Regression Using LP • Lesson 3: Radiation Therapy • Lesson 4: LP Models for Radiation Therapy	Sept 26, 2022 at 8: 00 a.m. Eastern
Week 6 Homework	Homework 6	Sept 26 at 8: 00 a.m. Eastern – Oct 6, at 11:59 p.m. Peer Assmt: Oct 6 at 11:59 Eastern – Oct 10 at 11:59 Eastern
Week 7	Module 13: Geometric Aspects of Linear Optimization • Lesson 1: Basic Geometric Objects in LP • Lesson 2: Extreme Points and Convex Hull • Lesson 3: Extreme Rays and Unbounded Polyhedron • Lesson 4: Representation of Polyhedrons	Oct 3, 2022 at 8: 00 a.m. Eastern

	Module 14: Algebraic Aspects of Linear Optimization • Lesson 1: Basic Feasible Solution • Lesson 2: Polyhedron in Standard Form • Lesson 3: Basic Feasible Solution in Standard Form LP • Lesson 4: Why We Care So Much About BFS	
Week 7 Homework	Homework 7	Oct 3 at 8: 00 a.m. Eastern – Oct 13 at 11:59 p.m. Peer Assmt: Oct 13 at 11:59 Eastern – Oct 17 at 11:59 Eastern
Week 8	Module 15: Simplex Method in a Nutshell • Lesson 1: Local Search - The General Idea • Lesson 2: Local Search - Specialized to LP • Lesson 3: How to Walk on the Edge • Lesson 4: When to Stop and Declare Victory Module 16: Further Development of Simplex Method • Lesson 1: Summarize Simplex Method • Lesson 2: Handling Degeneracy • Lesson 3: Phase I/Phase II Simplex Method • Lesson 4: An Example	Oct 10, 2022 at 8: 00 a.m. Eastern
Week 8 Homework	Homework 8	Oct 10 at 8: 00 a.m. Eastern – Oct 20 at 11:59 p.m. Peer Assmt: Oct 20 at 11:59 Eastern – Oct 24 at 11:59 Eastern

Midterm	Midterm Exam	Oct 17, 2022 at 8: 00 a.m. Eastern – Oct 24 at 11:59 p.m. Eastern
Week 9	Module 17: Linear Programming Duality • Lesson 1: Introduction to Duality Theory • Lesson 2: Lagrangian Relaxation and LP Duality • Lesson 3: Weak Duality and Strong Duality • Lesson 4: Table of Possibles and Impossibles • Lesson 5: Complementary Slackness Module 18: Robust Optimization • Lesson 1: Concept of Robustness • Lesson 2: Concept of Robustness in Example • Lesson 3: Robust Linear Program • Lesson 4: More Examples of Robust Linear Optimization	Oct 17, 2022 at 8: 00 a.m. Eastern
Week 9 Homework	Homework 9	Oct 17 at 8: 00 a.m. Eastern – Oct 27 at 11:59 p.m. Peer Assmt: Oct 27 at 11:59 Eastern – Oct 31 at 11:59 Eastern
Week 10	Module 19: Large-Scale Optimization Cutting Stock Problem • Lesson 1: Cutting Stock Problem • Lesson 2: Gilmore-Gomory Formulation • Lesson 3: Column Generation • Lesson 4: Column Generation for Cutting Stock Problem Module 20: Large-Scale Optimization • Lesson 1: Example for Column Generation	Oct 24, 2022 at 8: 00 a.m. Eastern

	• Lesson 2: Primal-Dual Relationship: Constraint Generation • Lesson 3: Primal-Dual Relationship: Pricing Problem and Separation Problem	
Week 10 Homework	Homework 10	Oct 24 at 8: 00 a.m. Eastern – Nov 3 at 11:59 p.m. Peer Assmt: Nov 3 at 11:59 Eastern – Nov 7 at 11:59 Eastern
Week 11	Module 21: Large-Scale Optimization Dantzig-Wolfe Decomposition • Lesson 1: Exploiting Special Structures of Large-Scale Optimization • Lesson 2: Dantzig-Wolfe Decomposition 1 • Lesson 3: Dantzig-Wolfe Decomposition 2 • Lesson 4: Dantzig-Wolfe Decomposition 3 • Lesson 5: Example Module 22: Nonlinear Optimization Modeling - Approximation and Fitting • Lesson 1: Linear Equations, Norm, and Least Square • Lesson 2: Function Fitting • Lesson 3: Normal Equation and Singular Value Decomposition • Lesson 4: Image Compression, Constrained Least Squares, and SVD	Oct 31, 2022 at 8: 00 a.m. Eastern
Week 11 Homework	Homework 11	Oct 31 at 8: 00 a.m. Eastern – Nov 10 at 11:59 p.m. Peer Assmt: Nov 10 at 11:59 Eastern – Nov 14 at 11:59 Eastern
Week 12	Module 23: Convex Conic Programming Introduction	Nov 7, 2022 at 8: 00 a.m. Eastern

	- Lesson 1: Convex Cones, Order, and Linear Conic Programming - Lesson 2: Second-Order Cone and SOCP - Lesson 3: PSD Cone and SDP Module 24: SOCP, SDP Examples - Lesson 1: Statistical Classification Problem - Lesson 2: Experimental Design - Lesson 3: Extremal Ellipsoid Problem	
Week 12 Homework	Homework 12	Nov 7 at 8: 00 a.m. Eastern – Nov 17 at 11:59 p.m. Peer Assmt: Nov 17 at 11:59 Eastern – Nov 21 at 11:59 Eastern
Week 13	Module 25: Discrete Optimization - Introduction - Lesson 1: Why Discrete Variables - Lesson 2: Discrete Optimization Challenges - Lesson 3: Computational Complexity Module 26: Discrete Optimization - Modeling With Binary Variables 1 - Lesson 1: Nonconvex Functions - Lesson 2: Nonconvex Sets and Logical Relations - Lesson 3: Logical Relations	Nov 14, 2022 at 8: 00 a.m. Eastern
Week 13 Homework	Homework 13	Nov 14 at 8: 00 a.m. Eastern – Nov 24 at 11:59 p.m. Peer Assmt: Nov 24 at 11:59 Eastern – Nov 28 at 11:59 Eastern

Week 14	Module 27: Discrete Optimization – Modeling With Binary Variables 2 • Lesson 1: Set Packing, Covering, Partitioning • Lesson 2: Graph and Network Problems Module 28: Discrete Optimization - Modeling Exercises • Lesson 1: Modeling Exercises - 1 • Lesson 2: Modeling Exercises - 2 • Lesson 3: Modeling Exercises - 3	Nov 21, 2022 at 8: 00 a.m. Eastern
Week 14 Homework	Homework 14	Nov 21 at 8: 00 a.m. Eastern – Dec 1 at 11:59 p.m. Peer Assmt: Dec 1 at 11:59 Eastern – Dec 5 at 11:59 Eastern
Week 15	Module 29: Discrete Optimization – Linear Programming Relaxation • Lesson 1: Linear Programming Relaxation • Lesson 2: Ideal Formulations Module 30: Discrete Optimization – Solution Methods • Lesson 1: Enumeration • Lesson 2: Cutting Plane Methods • Lesson 3: Branch-and-Bound Algorithm • Lesson 4: Heuristics	Nov 28, 2022 at 8: 00 a.m. Eastern
Week 15 Homework	Homework 15	Nov 28 at 8: 00 a.m. Eastern – Dec 6 at 11:59 p.m. Peer Assmt: Dec 6 at 11:59 Eastern – Dec 10 at 11:59 Eastern
Final	Final Exam	Dec 8, 2022 at 8:00 a.m. Eastern – Dec 15, 2022 at 11:59 p.m. Eastern

Course Materials

- All content and course materials can be accessed online
- There is no textbook for this course
- Reference books:
  - R. Rardin. “Optimization in Operations Research”, Prentice Hall, 1998.
  - S. Boyd and L. Vandenberghe, “Convex Optimization,” Cambridge University Press, 2004. Online: https://web.stanford.edu/~boyd/cvxbook/
  - A. Ben-Tal and A. Nemirovski, “Lectures on Modern Convex Optimization,” SIAM, 2001.

Technology/Software Requirements

- Internet connection (DSL, LAN, or cable connection desirable)
- PuLP optimization software (free download; see http://www.coin-or.org/PuLP/ -- Windows version and (for Mac users) a Linux version)
- CVX in Python: CVXOPT, CVXPY software (available at http://cvxopt.org and https://www.cvxpy.org/)
- CVX in MATLAB: CVX software (available at http://cvxr.com/cvx/)
- Python programming language (free download; see http://www.python.org). Preferably use the Anaconda distribution (http://www.anaconda.com)
- Adobe Acrobat PDF reader (free download; see https://get.adobe.com/reader/)