Course Syllabus

ISYE 6669

Deterministic Optimization

Spring 2021

Professors: Dr. Andy Sun and Dr. Shabbir Ahmed

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 UTC 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, books, or calculator/computers are allowed in the midterm and final quizzes.
- For midterm and final quizzes, you are allowed a blank sheet 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).

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. For special cases such as failed submissions due to system errors, missing grades, failed file uploads, emergencies that prevent you from submitting, personal issues, etc., a special email address will be provided in a discussion forum for you to directly contact the instructor and teaching assistants.

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	Jan 14, 2021 at 8: 00 a.m. Eastern
Week 1 Homework	Homework 1	Jan 14 at 8: 00 a.m. Eastern – Jan 24 at 11:59 p.m.

		Peer Assmt: Jan 24 at 11:59 Eastern – Jan 28 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	Jan 21, 2021 at 8: 00 a.m. Eastern
Week 2 Homework	Homework 2	Jan 21 at 8: 00 a.m. Eastern – Jan 31 at 11:59 p.m. Peer Assmt: Jan 31 at 11:59 Eastern – Feb 4 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	Jan 28, 2021 at at 8: 00 a.m. Eastern
Week 3 Homework	Homework 3	Jan 28 at 8: 00 a.m. Eastern – Feb 7 at 11:59 p.m. Peer Assmt: Feb 7 at 11:59 Eastern – Feb 11 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	Feb 4, 2021 at 8: 00 a.m. Eastern
Week 4 Homework	Homework 4	Feb 4 at 8: 00 a.m. Eastern – Feb 14 at 11:59 p.m. Peer Assmt: Feb 14 at 11:59 Eastern – Feb 18 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	Feb 11, 2021 at 8: 00 a.m. Eastern
Week 5 Homework	Homework 5	Feb 11 at 8: 00 a.m. Eastern – Feb 21 at 11:59 p.m.

		Peer Assmt: Feb 21 at 11:59 Eastern – Feb 25 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	Feb 18, 2021 at 8: 00 a.m. Eastern
Week 6 Homework	Homework 6	Feb 18 at 8: 00 a.m. Eastern – Feb 28, at 11:59 p.m. Peer Assmt: Feb 28 at 11:59 Eastern – Mar 4 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	Feb 25, 2021 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	Feb 25 at 8: 00 a.m. Eastern – Mar 7 at 11:59 p.m. Peer Assmt: Mar 12 at 11:59 Eastern – Mar 16 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	Mar 4, 2021 at 8: 00 a.m. Eastern
Week 8 Homework	Homework 8	Mar 4 at 8: 00 a.m. Eastern – Mar 14 at 11:59 p.m. Peer Assmt: Mar 14 at 11:59 Eastern – Mar 18 at 11:59 Eastern

Midterm	Midterm Exam	Mar 11, 2021 at 8: 00 a.m. Eastern – Mar 18 at 11:59 p.m. Eastern
Week 9	Module 17: Linear Programming Duality • Lesson 1: A Simple But Fundamental Trick for Deriving LP Dual • Lesson 2: Relation to Lagrangian Duality • Lesson 3: Weak and Strong Duality and Complementary Slackness • Lesson 4: Two-Person Zero-Sum Game Module 18: Robust Optimization • Lesson 1: Robustness and Its Wide Applications • Lesson 2: Robust Linear Program • Lesson 3: Two-Stage Robust Linear Program	Mar 11, 2021 at 8: 00 a.m. Eastern
Week 9 Homework	Homework 9	Mar 11 at 8: 00 a.m. Eastern – Mar 21 at 11:59 p.m. Peer Assmt: Mar 21 at 11:59 Eastern – Mar 25 at 11:59 Eastern
Week 10	Module 19: Nonlinear Optimization Modeling - Approximation and Fitting • Lesson 1: Gauss, Geodesy, and Linear Least-Squares Problem • Lesson 2: SVD, Matrix Approximation, and Image Compression • Lesson 3: Sparsity, Regularization, and Basis Pursuit • Lesson 4: Robust Approximation Module 20: Nonlinear Optimization Modeling - Statistical Estimation • Lesson 1: Parametric Distribution Estimation	Mar 18, 2021 at 8: 00 a.m. Eastern

	• Lesson 2: Nonparametric Distribution Estimation • Lesson 3: Computing Probability Bounds	
Week 10 Homework	Homework 10	Mar 18 at 8: 00 a.m. Eastern – Mar 28 at 11:59 p.m. Peer Assmt: Mar 28 at 11:59 Eastern – Apr 1 at 11:59 Eastern
Week 11	Module 21: Convex Conic Programming - Introduction • Lesson 1: Convex Cones and Generalized Inequality • Lesson 2: From LP Duality to Conic Duality • Lesson 3: Second-Order Conic Programming • Lesson 4: Semi-Definite Programming Module 22: Second-Order Conic Programming - Examples • Lesson 1: Projection and Separation • Lesson 2: Optimal Placement Problem • Lesson 3: Support Vector Machine • Lesson 4: Nonlinear Discrimination	Mar 25, 2021 at 8: 00 a.m. Eastern
Week 11 Homework	Homework 11	Mar 25 at 8: 00 a.m. Eastern – Apr 4 at 11:59 p.m. Peer Assmt: Apr 4 at 11:59 Eastern – Apr 8 at 11:59 Eastern
Week 12	Module 23: Second-Order Conic Programming - Advanced Modeling	Apr 1, 2021 at 8: 00 a.m. Eastern

	• Lesson 1: Conic Quadratic Representable Functions and Sets • Lesson 2: More "Exotic" CQr Functions • Lesson 3: Robust Linear Programming Revisited Module 24: Semi-Definite Programming - Advanced Modeling • Lesson 1: Eigenvalue Optimization as SDP • Lesson 2: Polynomial Optimization as SDP • Lesson 3: Optimal Power Flow and SDP Relaxation • Lesson 4: Structural Design	
Week 12 Homework	Homework 12	Apr 1 at 8: 00 a.m. Eastern – Apr 11 at 11:59 p.m. Peer Assmt: Apr 11 at 11:59 Eastern – Apr 15 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	Apr 8, 2021 at 8: 00 a.m. Eastern
Week 13 Homework	Homework 13	Apr 8 at 8: 00 a.m. Eastern – Apr 18 at 11:59 p.m. Peer Assmt: Apr 18 at 11:59 Eastern – Apr 22 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	Apr 15, 2021 at 8: 00 a.m. Eastern
Week 14 Homework	Homework 14	Apr 15 at 8: 00 a.m. Eastern – Apr 25 at 11:59 p.m. Peer Assmt: Apr 25 at 11:59 Eastern – Apr 29 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	Apr 22, 2020 at 8: 00 a.m. Eastern
Week 15 Homework	Homework 15	Apr 22 at 8: 00 a.m. Eastern – Apr 29 at 11:59 p.m. Peer Assmt: Apr 29 at 11:59 Eastern – May 3 at 11:59 Eastern
Final	Final Exam	May 3, 2021 at 8:00 a.m. Eastern – May 9, 2021 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) with Python 2.7.
- Adobe Acrobat PDF reader (free download; see https://get.adobe.com/reader/)