Title: Online Learning and Optimization
Instructors: Constantine Caramanis and Sanjay Shakkottai

Course Overview:
This course is a graduate level class on online learning and optimization. The course consists of two parts.

In the first part, we focus on algorithms for solving convex optimization problems. Of particular interest will be large scale problems that come from Machine Learning. We will cover first order methods, including gradient and subgradient methods, proximal gradient and Frank Wolfe, and mirror descent. We will also cover accelerated gradient methods, and stochastic gradient methods (SGD). Finally, we conclude this portion of the course with a discussion of Newton and quasi-Newton methods (second order methods). This part of the course will discuss the algorithms in detail, along with intuition for when, how and why they work, in addition to a careful analysis and proofs of convergence.

In the second part, we will study multi-armed bandits in stochastic and adversarial settings. Bandit problems are present in settings where decision-making is done in conjunction with learning and collecting new data. Such systems have an inherent tension between exploitation (using previously collected information to make the "best" decisions now) and exploration (making decisions that are not necessarily optimal, but better explores the search space to collect fresh data). Applications abound in a variety of settings, including online advertising, A/B testing, drug testing, recommendation systems, online resource allocation, reinforcement learning in games (e.g., AlphaGo Zero) and autonomous driving.

Pre-requisites:
Background in probability theory, linear algebra, and a first graduate course in convex optimization.

Textbooks:
1. Convex Optimization: Algorithms and Complexity, by Sébastien Bubeck, Foundations and Trends on Machine Learning, NOW Publishers, Vol. 8, No. 3-4, 2015.
2. Convex Optmization, by Stephen Boyd and Lieven Vandenberghe, by Cambridge University Press.
3. Bandit Algorithms, T. Lattimore and C. Szepesvari, To be published by Cambridge University Press, 2019. A preprint of the book is available on the web at: https://tor-lattimore.com/downloads/book/book.pdf
4. Online Learning and Online Convex Optimization, Shai Shalev-Shwartz, Foundations and Trends on Machine Learning, NOW Publishers, Vol. 4, No. 2, 2011.

Technical Requirements:

Before beginning this course, learners should check that their equipment meets the following technical requirements:

- Browser: latest Chrome or Firefox (Chrome preferred)
- OS: Mac 10.12/10.13/10.14, Linux or Windows 10 with at least 2GB of free space.
- Hardware: Dual Core 2.4 Ghz, 4GB RAM or better
- Internet connection: cable modem/DSL or better (500 kbps download, 300 kbps upload)
- Smartphone or scanner to take pictures and make PDFs of homework submissions
- Smartphone or other device capable of being used for dual-factor authentication

Office Hours: Office hours for your professor and TA are online and by appointment

Collaboration / Academic Honesty Policy

Collaboration is not allowed for homework or Quizzes. Every homework and quiz needs to be solved individually. We will check for duplicates. For the final project groups of up to 3 students are allows. Different groups are allowed to discuss ideas and share data, but no code.
The online course format allows for multiple methods of identity verification, collusion, collaboration and plagiarism monitoring and detection. A violation of the course policy may include (but is not limited to) the following:

- Providing your UT EID to any other person
- Collaborating or sharing information with another person regarding the material on any quiz, assessment or assignment, before, during and/or after any quiz, assessment or assignment
- Recording any quiz, assessment or assignment material in any format
- Failing to properly cite language, ideas, data, or arguments that are not originally yours
- The public (such that it can be viewed by more than one person) posting of any form of a test bank or group of questions from any assignment
- Consulting forbidden materials or sources of information

The University of Texas at Austin Academic Integrity principles call for students to avoid engaging in any form of academic dishonesty on behalf of yourself or another student. Grade-related penalties are routinely assessed ("F" in the course is not uncommon), but students can also be suspended or even permanently expelled from the University for scholastic dishonesty. If you have any questions about what constitutes academic dishonesty, please refer to the Dean of Students website or contact the instructor for this course.

You must agree to abide by the Honor Code of the University of Texas. You will not work with or collaborate with others in any way while completing any of the graded course assignments.

Assignments, Assessments, Evaluation, and Grading:

(i) Homework Part I (35%) There are 7 homework assignments in this Part. Note that the first two of the seven have nothing to submit, so you will all get full credit for these!
(ii) Homework Part II (35%) There are 7 homework assignments in this Part.

(iii) Midterm 1 (15%) This will cover all the material in Topic 1: Optimization
(iv) Midterm 2 (15%) This will cover all the material in Topic 2: Online Learning

Program Grade Requirements:
30 hour program
9 required hours
21 elective hours

Required courses, B- or higher
Elective courses, C or higher

To graduate, all students must have a graduate GPA avg of at least 3.00

Documented Disability Statement:
The University of Texas at Austin guarantees that students with disabilities have access to appropriate accommodations. You may request an accommodation letter from the Division of Diversity and Community Engagement, Services for Students with Disabilities [https://diversity.utexas.edu/disability/].

If you have approved accommodations for the course, please contact us to arrange them. Please do this as soon as possible, so that you can have the benefit of the accommodations throughout the duration of the course.

Course Etiquette:
We expect that you will treat online discussions as though you are having a civil, respectful discussion with your fellow classmates in the same classroom. Please refrain from using profanity or any euphemisms for profanity. Please do not bait other commenters or personally attack them. Please do not use sarcasm in a way that can be misinterpreted negatively. And please do not make the same point over and over again. In short, please just respect the right of your colleagues to ask questions and discuss their opinions about the subject matter of our course on the discussion board. Violators of these discussion rules will simply be shut out from all class communications—email, Piazza, and office hours.

Behavior Concerns Advice Line:
If you are worried about someone who is acting differently, you may use the Behavior Concerns Advice Line to discuss by phone your concerns about another individuals behavior. This service is provided through a partnership among the Office of the Dean of Students, the Counseling and Mental Health Center (CMHC), the Employee Assistance Program (EAP), and The University of Texas Police Department (UTPD). Call 512-232-5050 or visit
https://besafe.utexas.edu/behavior-concerns- advice-line

Academic Advisor Support:
If you have additional questions or require support from an academic advisor, please contact the program coordinator at msonline@cs.utexas.edu.

Topics and Syllabus Outline:

Part I

1. Convex sets and Convex functions, including basic definitions of convexity, smoothness and strong convexity.
2. First order optimality conditions for unconstrained and constrained convex optimization problems.
3. Gradient and subgradient descent: Lipschitz functions, Smooth functions, Smooth and Strongly Convex functions.
4. Oracle Lower Bounds
5. Accelerated Gradient Methods
6. Proximal and projected gradient descent. ISTA and FISTA.
7. Mirror Descent
8. Frank Wolfe
9. Stochastic Gradient Descent
10. Newton and Quasi-Newton Methods

Part II

1. Stochastic bandits with finite number of arms: Explore and commit algorithm, UCB algorithm and regret analysis.
2. Adversarial bandits with finite number of arms: Exponential weighting and importance sampling, Exp3 algorithm and variants.
3. Multi-armed Bandit (MAB) lower bounds: minimax bounds, problem-dependent bounds.
4. Contextual bandits: Bandits with experts -- the Exp4 algorithm, stochastic linear bandits, UCB algorithm with confidence balls (LinUCB and variants).
5. Contextual bandits in the adversarial setting: Online linear optimization (with full and bandit feedback), Follow The Leader (FTL) and Follow the Regularized Leader (FTRL), Mirror Descent.
6. Online Classification: Halfing algorithm, Weighted majority algorithm, Perceptron and Winnow algorithms (with connections to Online Gradient Descent and Online Mirror Descent).
7. Other Topics: Combinatorial bandits, Bandits for pure exploration, Bandits in a Bayesian setting, Thompson sampling