Lecture 00: Theoretical Computer Science Toolkit (CS 58500)

Course Content

- Introduce Foundational Topics in Theoretical Computer Science & Machine Learning
  - Mathematical Foundations
  - Wide Applications in Computer Science

About the Instructors

- Hemanta K. Maji: Cryptography & Theory (website)
- Paul Valiant: Algorithms and Complexity, Machine Learning, Fluid Dynamics, and the Brain (website)

Tentative List of Topics

Mathematical Basics

- Inequalities: Jensen's Inequality and consequences
- Summations/Integrals
- Stirling Approximation

Tentative List of Topics

Concentration Inequalities

- Markov Inequality, Chebyshev Inequality
- Chernoff-Hoeffding Bound
- Azuma's Inequality
- Talagrand Inequality

Tentative List of Topics

Selected Topics in Convex Analysis and Optimization

- Introduction to convex sets and functions
- Convex set results: Separating hyperplane and Caratheodory's theorems
- Convex function results: Jensen's inequality and applications, Legendre-Fenchel transformation
- Lagrangian duality and Karush-Kuhn-Tucker (KKT) conditions
- Strong convexity and oracle complexity of gradient descent
- Gradient descent and its variants

Tentative List of Topics

Foundations of Spectral Methods

- Positive semidefiniteness, Spectral and singular value decompositions
- Courant–Fischer–Weyl minimax theorems
- Perron–Frobenius theory
- Matrix norms and perturbation theory

Tentative List of Topics

Discrete Fourier Analysis on the Boolean Hypercube

- BLR Linearity Testing
- Randomness Extraction
- Randomness Extraction and Left-over Hash Lemma
- Hypercontractivity
- KKL Theorem
- Pseudorandomness and Goldreich-Levin Theorem

Course Outline: Grand Aim

- Covers fundamental techniques and a range of mathematical tools that underlie today's research in theoretical computer science
  - Essential knowledge for students pursuing research in theoretical computer science or machine learning theory
- Target: Current graduate and undergrad students interested in pursuing research in these areas
  - Undergraduates interested in taking the course should contact the instructor for permission

Prerequisites

Mastery of the material covered in

- Calc III (Math 261)
- Linear Algebra (Math 265)
- Probability (STAT 416)
- Foundations of CS (CS 182)
- Analysis of Algorithms (CS 381 or CS 580)

Read the course website and the course policy

Course Instruction

- Board-work
- Lecture notes (in next couple of days)
- Pointers to a lot of reading materials
- General Pointers to books and other related courses
  - No official course book
  - Lecture roughly based on surveys on the topics
  - The course syllabus is flexible, and student interest will influence it

Grading

- 45% Homework (roughly five)
- 30% Midterm (a late midterm: around the 10-week mark)
- 20% Final Group Presentation
- 5% Class Participation

How to Use this Course?

- For Grades
  - Submit Homework, perform in Exams, and Participate in Class
- For Research
  - Solve extra-credit problems, read additional materials, discuss with instructors by scheduling appointments, and target to find a research topic of choice

Office Hours

- Office hour with Instructors: By Appointment Only
- Office hour with TA: One hour that is agreeable to the TA and all students (2 days / week)
- Details coming up soon on Brightspace

Concluding Remarks

- This course will be challenging; We are here to work together
- We will collaboratively learn from each other
- Read the course webpage