CSCI 670, Fall 2021
Advanced Analysis of Algorithms

Course Info	Course outline

Course Info:

Course descriptions and objectives	In Spring 2015, CS department has decided to make CSCI 670 a required class for all its Ph.D. students. While I personally never prefer to make any class that I teach a required class -- *computer science* has evolved so rapidly for me or maybe anyone to determine what each successful student should take -- this requirement has inspired me to modernize this class. In the age of Big Data, efficient algorithms are now in higher demand more than ever before. While Big Data takes computing into the asymptotic world envisioned by our pioneers, it also challenges the classical notion of efficient algorithms: Algorithms that used to be considered efficient, according to polynomial-time characterization, may no longer be adequate for solving today's problems. It is not just desirable, but essential, that efficient algorithms should be scalable. In other words, their complexity should be nearly linear or sub-linear with respect to the problem size. Thus, scalability, not just polynomial-time computability, should be elevated as the central complexity notion for characterizing efficient computation. This revision -- an evolving project -- has shifted the focus of this class towards "modern" algorithm design and analysis, both in techniques/methodologies and example problems. While the class materials cover mostly known and well-established results in the literature, I will also cover topics of potential research interests. I hope each student will be able to learn something to benefit his/her research. Students in the class are expected to have a reasonable degree of mathematical sophistication, and to be familiar with the basic notions of algorithms and data structures, discrete mathematics, probability, and complexity theory. Specifically, the following will be assumed: • Mathematical Proofs, in particular induction and contradiction. • Asymptotic notation (Big-O, Omega, Theta), how to apply them. • Basic data structures: arrays, linked lists, trees, balanced trees, heaps (priority queues), graphs. • Basic graph algorithms: connected components, BFS, DFS. • Other basic algorithms: binary search, sorting, median selection. • Discrete mathematics: evaluating sums and simple recurrences. • Basic complexity theory: Turing machines, computability, NP completeness, polynomial-time reduction. Undergraduate classes in these subjects should be sufficient. If you have doubts about meeting these prerequisites, please contact the instructor. **This is a theory class. Students will be required and tested not just to design algorithms but also to rigorously characterize their performance. This is also a fast-paced class. If a student does not do the reading assignments and homeworks in a timely fashion, then they will experience limited benefit from the class.**
Instructor	**Professor Shang-Hua Teng** Office hours: MW: 3:50 - 4:30 (after the lectures) or by appointment; Email : shanghua[@]usc.edu
TA	**Yusuf Hakan Kalayci** Office hours: 16:30-17:30 on Wednesdays Email: kalayci@usc.edu
Textbook	• BOOK 1: **Algorithm Design** Jon Kleinberg and Eva Tardos • BOOK 2: **Scalable Algorithms for Data and Network Analysis** Shang-Hua Teng The class will also cover additional material drawn from research papers as well as other books in Theoretical Computer Science.
Lectures	14:00 -- 15:50 Monday and Wednesday, in room VHE 217
In-Person Classroom Mask Policy	**The University mask policy (based on the current CDC and LA County recommendations) will be strictly implemented in the classroom: At all times, everyone must have a mask properly covering their nose and mouth. During the two-hour lecture, we will have two regular breaks for students to go outside the building to drink water and have some fresh air.**
Grades	• **10 points** - 5 points - two *theoretical thinking projects* • **45 points** - 15 points each - three *quizzes on homeworks* (closed book & notes)

	• **50 points** - 25 points each - *midterm and final exams* (open book)
Homeworks	
Integrity	Plagiarism and other anti-intellectual behavior will be dealt with severely. This includes the possibility of failing the course or being expelled from the University.

Course Outline (subject to changes)

Lec#	Date	Topics and/or Events	Required Reading	"Fun" Research Reading
1	08/23	**General Topics:** Class Organization: Theoretical Computer Science **Specific Subjects:** algorithms and complexity theory: a quick review ** Type of Computational Problems Decision Search Optimization Games, puzzles, and interactions Game theory and dynamics Type of Algorithms Sequential Parallel Distributed Quantum On-line Complexity Theory and Algorithm Analysis P-Space, NP, PLS, PPAD polynomial-time algorithms scalable algorithms **	Book 1: Chapters 1-3 Search on the Web. For example: "google P NP" "google linear programming" "google graph partitioning" "google clustering" "google nearest neighbors" "google Nash Equilibrium" "google Page Rank" "google network flow" "google scalable algorithms"	Lipton's brilliant blog: "Goedel's Lost Letter and P=NP"
2	08/25	**General Topics:** Algorithms and Heuristics **Specific Subjects:** merging files, merging lists, Huffman codes, mergesort revisit clustering and minimum spanning trees **Algorithmic Techniques:** greedy algorithms **Mathematical Concepts:** prefix-free codes minmum spanning trees low-stretch spanning trees	Book 1: Chapter 4	Noga Alon, Richard M. Karp, David Peleg, and Douglas West, A Graph-Theoretic Game and Its Application to the k-Server Problem Michael Elkin, Yuval Emek, Daniel A. Spielman, Shang-Hua Teng Lower-Stretch Spanning Trees
3	08/30	**General Topics:** Graph Algorithms **Specific Subjects:** shortest paths in a graph **Algorithmic Techniques:** greedy algorithms **Mathematical Concepts:** shortest path graph metrics network routing	Book 1: Chapter 4	Thorup and Zwick: Approximate distance oracles, ournal of the ACM (JACM), Volume 52 Issue 1, January 2005
4	09/01	**General Topics:** Network Analysis **Specific Subjects:** social influence **Algorithmic Techniques:** greedy algorithms submodular function maximization **Mathematical Concepts:** network process triggering models submodular functions	David Kempe, Jon Kleinberg, and Eva Tardos, Maximizing the Spread of Influence through a Social Network George Nemhauser, Laurence Wolsey, and Marshall Fisher: An analysis of the approximations for maximizing submodular set functions I. Mathematical Programming, 14(1), 265-294, 1978 Andreas Krause, Submodular Function Maximization	Christian Borgs, Michael Brautbar, Jennifer Chayes, Brendan Lucier, Maximizing Social Influence in Nearly Optimal Time Y. Tang, X. Xiao, and Y. Shi. Influence maximization: near-optimal time complexity meets practical efficiency.

			[Theorem 1.5 (Page 6-7)]	In Proceedings of the ACM SIGMOD International Conference on Management of Data, SIGMOD, pages 75-86, 2014 Y. Tang, Y. Shi, and X. Xiao. Influence maximization in near-linear time: A martingale approach. In Proceedings of the ACM SIGMOD International Conference on Management of Data, SIGMOD, pages 1539-1554, 2015 [Wei Chen, Shang-Hua Teng, Interplay between Social Influence and Network Centrality: Shapley Values and Scalable Algorithms]
5	09/06	**Labor Day (No Class)**		
6	09/8	**General Topics:** Optimization and Approximation **Specific Subjects:** set cover **Algorithmic Techniques:** greedy algorithms **Mathematical Concepts:** potential analysis	Book 1: Chapter 11 (11.1 -- 11.5, 11.8)	
7	09/13	**General Topics:** Geometric Data **Specific Subjects:** clustering dimension reduction **Algorithmic Techniques:** iterative algorithms local search; potential games **Mathematical Concepts:** Voronoi diagrams well-separated clusters outliers clustering stability singular value decomposition	S. Lloyd. Least squares quantization in PCM. IEEE Transactions on Information Theory, 28(2), 129-137, 2006 Search on the Web. For example: "google Voronoi diagram" "google SVD" "google dimension reduction" "google potential games" "google Polynomial Local Search (PLS)"	D. Arthur, B. Manthey, and H. RoLlin. Smoothed analysis of the k-means method. Journal of the ACM, 58(5), 19:1-19:31, 2011 [Balcan, Blum, and Gupta: Approximate clustering without the approximation]
8	09/15	**2:00-3:00pm: Quiz 1** **3:00-3:50pm:** Discussion: network centrality		
9	09/20	**General Topics:** Geometric Data **Specific Subjects:** robust statistics median and extensions **Algorithmic Techniques:** sampling and randomization local data analysis evolutionary algorithms **Mathematical Concepts:** centerpoints VC dimensions tail analysis convex geometry: the theorems of Radon and Helly	Book 2: Chapter 5	V. N. Vapnik and A. Y. Chervonenkis. On the uniform convergence of relative frequencies of events to their probabilities. Theory of Probability and Its Applications, 16, 264-280, 1971 M. Hubert and P. J. Rousseeuw. The catline for deep regression. J. Multivariate Analysis, 66:270-296, 1998 N. Amenta, M. Bern, D. Eppstein, and S.-H. Teng. Regression depth and center points. Discrete &

				Computational Geometry, 23(3), 305-323, 2000
10	09/22	**General Topics:** Geometric Data **Specific Subjects:** geometric divide and conquer **Algorithmic Techniques:** divide and conquer generalized binary search **Mathematical Concepts:** NNG point location data structures	Book 2: Chapter 5 Miller, Teng, Thurston, Vavasis: Separators for sphere-packings and nearest neighbor graphs, Journal of the ACM, Volume 44 Issue 1, Jan. 1997	Bentley: Multidimensional divide-and-conquer, Communications of the ACM, Volume 23 Issue 4, April 1980 Lipton, Rose, and Tarjan: Generalized nested dissection, SIAM Journal on Numerical Analysis 16 (2): 346-358 Gilbert and Tarjan: The analysis of a nested dissection algorithm, Numerische Mathematik 50 (4): 377-404.
11	09/27	**General Topics:** Geometric Data **Specific Subjects:** geometric separators and clustering geometric graphs: grids, nearest neighbor graphs (NNG), planar graphs, and meshes **Algorithmic Techniques:** sampling and randomization divide and conquer **Mathematical Concepts:** planar and geometric separator theorems geometric duality Koebe embedding and the lake problem geometric duality Delaunay triangulations	Book 2: Chapter 5 Lipton and Tarjan: "A Separator Theorem for Planar Graphs," SIAM J. Appl. Math. 36, 177-189 (1979) Miller, Teng, Thurston, Vavasis: Separators for sphere-packings and nearest neighbor graphs, Journal of the ACM, Volume 44 Issue 1, Jan. 1997 Spielman and Teng: Disk Packings and Planar Separators, SCG 96: 12th Annual ACM Symposium on Computational Geometry, pages 349-358.	Spielman and Teng, "Spectral partitioning works: Planar graphs and finite element meshes", Linear Algebra and its Applications Volume 421, Issues 2-3, 1 March 2007, Pages 284-305 (Special Issue in honor of Miroslav Fiedler)
12	09/29	**General Topics:** FFT **Specific Subjects:** machine learning perspectives of FFT Discrete Fourier Transform inverse DFT **Algorithmic Techniques:** divide and conquer algorithmic view of proof by induction **Mathematical Concepts:** complex numbers Fundamental Theorem of Algebra	Book 1: Chapter 5 Search on the Web. For example: "google FFT" "google Discrete Fourier Transform" "google Fourier Transform" "google Fourier Analysis"	
13	10/04	**General Topics:** FFT **Specific Subjects:** integer multiplication **Algorithmic Techniques:** divide and conquer **Mathematical Concepts:** linear algebra: review polynomials representations evaluation interpolation convolution and polynomial multiplication	Book 1: Chapter 5 Search on the Web. For example: "google FFT" "google Discrete Fourier Transform" "google Fourier Transform" "google Fourier Analysis"	
14	10/06	**Midterm: good luck**		
15	10/11	**General Topics:** Binary Search in Graphs	Ehsan Emamjomeh-Zadeh, David Kempe, Vikrant Singhal: Deterministic and Probabilistic Binary Search in Graphs. In Proc. of STOC 2016.	
16	10/13	**General Topics:** Interactive Learning	Ehsan Emamjomeh-Zadeh, David Kempe: A General Framework for Robust Interactive Learning. In Proc. of NIPS 2017.	

17	10/18	**General Topics:** Graph Algorithms **Specific Subjects:** maximum flow and minimum cuts in a network **Algorithmic Techniques:** iterative algorithms **Mathematical Concepts:** linear programming duality	Book 1: Chapter 7	Tom Leighton and Satish Rao: Multicommodity max-flow min-cut theorems and their use in designing approximation algorithms, Journal of the ACM, Volume 46 Issue 6, Nov. 1999
18	10/20	**General Topics:** Network Analysis **Specific Subjects:** network centrality PageRank; personalized PageRank **Algorithmic Techniques:** sampling and randomization local network exploration simulated annealing **Mathematical Concepts:** Markov chain matrix powers random-walk matrix polynomials	Book 2: Chapter 3	S. Brin and L. Page. The anatomy of a large-scale hypertextual Web search engine. Computer Networks, 30(1-7), 107-117, 1998
19	10/25	**General Topics:** Network Analysis **Specific Subjects:** significant PageRank identification **Algorithmic Techniques:** sampling and randomization local network exploration simulated annealing **Mathematical Concepts:** personalized PageRank matrix centrality conforming Markov chain	Book 2: Chapter 3	
20	10/27	**General Topics:** Spectral Graph Theory **Specific Subjects:** Laplacian matrices **Algorithmic Techniques:** spectral method **Mathematical Concepts:** clusterability conductance spectral embeddings Rayleigh quotient	Book 2: Chapter 4	M. Fiedler. Algebraic connectivity of graphs. Czechoslovak Mathemat- ical Journal, 23(2):298 - 305, 1973 F. R. K. Chung. Spectral Graph Theory (CBMS Regional Conference Series in Mathematics, No. 92). American Mathematical Society, Feb. 1997.
21	11/01	**Quiz 2**		
22	11/03	**General Topics:** Spectral Graph Theory **Specific Subjects:** graph partitioning **Algorithmic Techniques:** sweep and spectral partitioning local clustering algorithms **Mathematical Concepts:** Cheeger's inequality	Book 2: Chapter 4	Spielman and Teng, "Spectral partitioning works: Planar graphs and finite element meshes", Linear Algebra and its Applications Volume 421, Issues 2-3, 1 March 2007, Pages 284-305 (Special Issue in honor of Miroslav Fiedler) Frank McSherry, Spectral Partitioning of Random Graphs, FOCS '01
23	11/08	**General Topics:** Spectral Graph Theory **Specific Subjects:** scalable Laplacian paradigm **Algorithmic Techniques:** SDD solvers **Mathematical Concepts:** spectral approximation learning on graphs	Book 2: Chapter 7	J. Batson, D. A. Spielman, N. Srivastava, and S.-H. Teng. Spectral sparsification of graphs: Theory and algorithms. Communications of the ACM, 56(8):87-94, Aug. 2013.