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Syllabus for MATH 191
MATH 191 Variable Topics: Graphs and Networks
Department of Mathematics, UCLA
Winter Quarter 2015

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Lecture: MWF: 3:00-3:50pm, MS 5137

Instructor: Mihai Cucuringu

Office:	MS 7310
Email:	mcucurin@ucla.edu
Office Hours:	Monday 5-6:30 pm, Thursday 5-6:30 pm

Reader: Joseph Woodworth

Office:	MS 7630
Email:	jwoodworth@math.ucla.edu

Course Description: This is a project-based course about graphs and networks, that combines both mathematical and empirical approaches. We will consider a variety of graphs that have been studied extensively in the sciences and engineering literatures. We will study social networks, the web and internet graphs, protein interaction networks, geometric and random graphs, preferential attachment and small-world models, but also topics such as random walks on graphs, spectral graph theory, isoperimetric ratio and connection with the spectrum of the graph Laplacian, measures of centrality in networks including the PageRank algorithm, diffusion, gossip and rumor spreading, the evolution of graphs, electrical flows and their algorithmic implications. Finally, we will consider various notions of similarity and distance between the nodes of a graph, clustering and community detection, and graph drawing.

Textbook: We will (most of the time) follow the book *Networks: An Introduction, by M. E. J. Newman.* See the end of the syllabus for a tentative list of chapters/topics to be covered.

Recommended Prerequisites: discrete mathematics (at MATH 61 level), linear algebra (MATH 33A), and elementary probability. Some familiarity with MATLAB (or other programming languages) is useful but can be learned.

Programming: For the experimental/empirical parts of the course, I will be using MATLAB, and share with you any scripts that I put together. For projects and homework problems, I advise that you use MATLAB. I can help you with MATLAB or R, but for any other languages you are on your own.

Exams:

- Midterm: take home, posted on February 5, due on February 9 in class.

- Final exam: consists of a project for which you will deliver an in-class presentation and write up a research report. The presentations will take place in the same classroom during the last two (possibly three) lectures in the last week of classes (the week of March 9). You may work in teams; more details on this will follow as we get closer to the second half of the quarter.

Final letter grade:

- Your final grade is calculated from the average homework grade (scaled to the range 0-100), scribe notes for a lecture, midterm and final project, as a weighted average with the following weights:

Homework	15%
Scribe notes	10%
Midterm	25%
Final Project	50%

- The numeric cut-offs for computing the final letter grade will take into account the overall performance of the class.

Appeals:

- As a rule of thumb, you should only appeal on correctness, and not on the amount of partial credit you received.

- Appeals for the midterm and final projects must be submitted to the instructor within one week of the exam grading.

Homework: The following rules apply to homework:

- I will occasionally assign homework throughout the course. It is important that you do the homework if you want to understand the material taught in class, both the theoretical and the experimental problems. I will announce in class when homework is posted online and when it is due.

- **Write-up:** You must always justify your solution to each homework problem. Correct final answers without a correct or incomplete justification will receive zero or very few points.

- **Group work:** It is ok to work together on the homework, **in groups of size at most 5**. However, when it comes time for you to write up the solutions, I expect you to do this on your own. It would be best for your own understanding if you put aside your notes from the discussions with your classmates and write up the solutions entirely from scratch.

- For the experimental problems, it goes without saying that you should write your own code. It is ok to ask others for help with programming, but please make sure you understand what you code.

- **Submission format:** Please attach the cover page (found at the end of this syllabus) as the first page to each and every homework assignment you hand in. It is fine if you handwrite you own version of this cover page.

Topics covered

- Overview of various types of real-world networks

- Basic definitions from graph theory

- Weighted graphs; Cocitation and Bibliographic Coupling; Acyclic graphs and their properties

- Bipartite graphs and one-mode projections; Hypergraphs

- Connectivity; Trees and Forests

- Planar graphs; Chromatic number; Graph minors

- Counting walks on graphs

- Geodesic paths; Diameter; Girth

- Eulerian paths and cycles; Hamiltonian paths and cycles

- Laplacian Eigenmaps and their application to network analysis

- Spectral graph theory; Eigenvalues of the adjacency matrix; Bounds on the average and max degree

- Spectral properties of the Random-Walk Laplacian and the Combinatorial Laplacian; d-regular graphs, complete graphs K_n, bipartite graphs, bipartite complete graphs $K_{m,n}$

- Isoperimetric ratio, conductance and the spectral gap

- Network centrality measures: degree, closeness centrality, betweenness centrality, eigenvector centrality, Katz centrality, subgraph centrality

- Graph similarity, Louvain method by Blondel et al.

- Authority Hub Score (Kleinberg, 1999)

- Structural equivalence vs. regular equivalence; cosine similarity, Pearson coefficients

- Complexity of computing eigenvectors

- Graph partitioning and community detection, the Kernighan-Lin algorithm, spectral partitioning, the Network Community Profile Plot (NCP)

- Erdős-Rényi random graphs: mean degree, degree distribution, clustering coefficient, giant component, connectivity

- Power-law graphs

- Small World models, clustering coefficient, navigation in a small world (Kleinberg's paper)

- Preferential Attachment Models; Price Model, Barabási Albert Model

- Graphs in Algorithmic Game Theory

- Additional topics covered by the final research projects:
    - spectral-based vertex similarity and random-walk betweenness centrality
    - a local-to-global approach for vertex and graph similarity via the generalized condition number
    - a gravity model for spatial networks, and re-drawing the map of the US via constrained clustering
    - a centrality measure via the effective resistance embedding
    - global alignment of networks
    - co-clustering and bipartite clustering
    - constrained clustering and forecasting locations in Twitter data
    - vertex similarity via angular synchronization
    - correlation clustering

Scribe Notes

For each lecture, one or two students will be responsible for scribing the lecture notes. Here are some useful tips:

1. Come to class!

2. Take careful notes during class of what I write on the blackboard, of what I explain sometimes without writing down, and of other students' questions and comments.

3. Put together your notes into a latex document, where you make a clear description in complete full sentences of what has been covered in class. Somebody who missed class or was late for class that day should be able to make full sense of all your notes. Use the book as a reference if you feel something is not clear in your notes, or you want to add in more details. Make sure you check for spelling mistakes, and read over the document a few times.

4. Use latex to prepare your documents, I attached a latex template that you should use *Template-Scribe-Notes-191*

5. Include figures where appropriate. Sometimes it may be easier to scan a figure from the textbook, or find a similar one online.

6. Here are some websites that you may find useful if you are a beginner in LaTex:

   `http://www.latex-project.org/`

   `http://www.personal.ceu.hu/tex/cookbook.html`

   `http://www.thestudentroom.co.uk/wiki/LaTex`

7. Email me both the latex file (together with figures, if any) and the compiled PDF, within one week of the class for which you volunteered to scribe.

8. I will post your scribe notes online, possibly after making some small revisions myself. Usually, you will be asked to make some more revisions based on my comments; once you do so, I will post the polished version online.

MATH 191: Graphs and Networks
Cover Page

Winter 2015

Homework #	
Last name	
First name	
Student ID	

Worked with (list at most 4 full names):

1.	
2.	
3.	
4.	