Course Syllabus: CS 7280

Course Information/Syllabus

It is often the case that *complex systems*, both living and man-made, can be represented as static or dynamic *networks* of many interacting components. These components are typically much simpler in terms of behavior or function than the overall system, implying that the additional complexity of the latter is an *emergent network property.*

Network science is a relatively new discipline that investigates the topology and dynamics of such complex networks, aiming to better understand the behavior, function, and properties of the underlying systems.

The applications of network science cover physical, informational, biological, cognitive, and social systems.

In this course, we will study algorithmic, computational, and statistical methods of network science, as well as various applications in social, communication, and biological networks.

A significant component of the course will focus on the overlap between statistics, machine learning and network science, covering methods for network inference, generative network models, embeddings using deep neural networks, and other state of the art topics.

Students will:

- Understand what ***"network science"*** means, how it relates to other disciplines (graph theory, data mining, machine learning, etc), and how it is useful in practice
- Learn how to detect, quantify and interpret important properties of real networks, such as power-law degree distribution, "small world" efficiency and clustering, assortativity, hierarchy, modularity, and others
- Learn how to identify the most important nodes and links in a network through network centrality metrics and core identification algorithms
- Design and analyze algorithms that compute "communities" of highly clustered nodes, and learn how to compare such algorithms
- Appreciate the value of network modeling, and learn several approaches to model a static or dynamic network

- Understand the "network inference" problem and learn statistical and machine learning methods that estimate a network from noisy data
- Understand how representation learning *(and deep learning in particular)* is applied to network science
- Learn how to model and predict network epidemics, influence, cascades, and other *"spreading"* phenomena

- Understand how the structure (topology) of a network affects the function and dynamic activity on that network
- Become familiar with several state-of-the-art research directions in network science

Prerequisites:

Some knowledge (at the level of a good undergrad course) of calculus, probability, linear algebra, and Python programming is necessary.

Please take the Prerequisites Quiz to check your background. It is ok if you do not answer all questions correctly -- but in that case, do you understand the correct answer?

The course hopes to attract students from different academic backgrounds and research interests (including math, physics, engineering, biology, neuroscience or sociology). Consequently, the instructor tries to keep the course as "self-contained" as possible.

Grading Process:

This course will use the following grade breakdown:

- Projects (5 in total): 65%
- One quiz for each lesson (14 in total): 35%

The final grade will be determined based on your final weighted grade average (no "curving"), as follows:

A: 90-100%

B: 80-90%

C: 70-80%

D: 60-70%

F: Below 60%

The weighted average percentage will be rounded to the nearest integer.

Course Policies:

You cannot take this course for *"Audit"*. Doing the assignments is essential.

All work for this class is to be done individually. You are strongly urged to familiarize yourself with the **GT Student Honor CodeLinks to an external site.** rules. Specifically, the following is not allowed:

- Copying, with or without modification, someone else's work when this work is not meant to be publicly accessible *(e.g., a classmate's program or solution. **This includes copying substantial code or answers from AI tools and software such as LLM's like ChatGPT, Claude, or Gemini**)*.
- Submission of material that is wholly or substantially identical to that created or published by another person or persons, without adequate credit notations indicating authorship *(plagiarism)*.
- Putting your projects on public Github. If a student *(in the future)* copies your codes/projects, the student obviously violates the honor code but you will also be implicated.

You are encouraged to discuss problems and papers with others as long as this does not involve copying of code or solutions. Any public material that you use *(open-source software, help from a text, or substantial help from a friend, etc...)* should be acknowledged explicitly in anything you submit to us. If you have any doubt about whether something is legal or not please do check with the class Instructor and the Head TA. We will be monitoring submissions for plagiarism, and will submit suspicious cases to the Office of Student Integrity.

Extensions:

You can ask for a deadline extension only due to health issues (including mental health) but with appropriate medical documentation. Contact the Head TA by email for guidance on this policy.

- Lesson One: What is Network Science?
  - What is (not) network science?
  - The main premise of network science

- History and relation to graph theory, physics, sociology, and other disciplines
- Examples of networks from different application domains

- Lesson Two: Relevant Concepts From Graph Theory
  - Undirected, directed, signed, weighted and spatial networks
  - Paths, connected components, random walks, etc
  - Directed Acyclic Graphs
  - Bipartite graphs
  - Max-flow/min-cut

- Lesson Three: Degree Distribution and ER Graphs
  - Degree distribution
  - Friendship paradox
  - ER graphs and their degree distribution
  - Giant component size in ER graphs
  - Assortative vs disassortative networks

- Lesson Four: Random vs. Real Graphs and "Scale Free" Networks
  - The degree distribution of real-world networks
  - Power-law degree distributions
  - Preferential attachment model
  - How to detect a power-law and estimate the exponent
  - Configuration model and degree-preserving randomization

- Lesson Five: Network Paths, Clustering and The “Small World” Property
  - Clustering and transitivity in networks
  - Diameter and characteristic path length
  - Small-world networks and the Watts-Strogatz model
  - Network motifs

- Lesson Six: Centrality and Netork-core Metrics and Algorithms
    - Link-based centrality metrics
    - Path-based centrality metrics
    - k-core decomposition
    - Core-periphery structure
    - Rich-club set of nodes

- Lesson Seven: Community Detection and Hierarchical Modularity
    - Hierarchical clustering in networks
    - Modularity metric
    - Algorithms for modularity maximization
    - Limitations of modularity
    - Hiearchical modularity

- Lesson Eight: Advanced Topics in Community Detection
    - Overlapping communities
    - Dynamic communities
    - Comparing community structures
    - The role of nodes within and between communities
    - Applications of community detection

- Lesson Nine: Network Contagion and Epidemics
    - Epidemics on networks
    - Epidemic modeling (SI, SIS, SIR, etc) under homogeneous mixing
    - Epidemic modeling under arbitrary degree distributions
    - Basic reproductive number and superspreaders

- Lesson Ten: Influence Phenomena On Networks
    - The linear threshold model and the Independent cascades model
    - Empirical studies in information and behavior spreading

- Seeding strategies on how to maximize influence
- Cascades and community structure

- Lesson Eleven: Other Dynamic Processes Of/On Networks
    - Percolation, random failures, and targeted attacks on networks
    - Search on networks
    - Synchronization on networks
    - Coevolutionary networks

- Lesson Twelve: Models of Static and Dynamic Networks
    - Stochastic network models that generate power-law degree distributions
    - Optimization-based network models
    - Stochastic block models
    - Hierarchical Random Graphs

- Lesson Thirteen: Statistical Analysis of Network Data
    - Network sampling methods
    - Estimation of network metrics
    - Association networks
    - Network tomography

- Lesson Fourteen: Machine Learning meets Network Science
    - Node embeddings
    - Graph neural networks
    - Deep generative network models
    - Limitations and applications of graph neural networks

Course Summary:

Date	Details	Due
Thu Jan 9, 2025	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Wed Jan 15, 2025	Quiz Lesson-1: Quiz (graded)	due by 8am
	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Jan 16, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Jan 20, 2025	Quiz Lesson-2: Quiz (graded)	due by 8am
Wed Jan 22, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Jan 23, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Jan 27, 2025	Quiz Lesson-3: Quiz (graded)	due by 8am
	Assignment Module One: Project	due by 8am
Wed Jan 29, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Jan 30, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am

Date	Details	Due
Mon Feb 3, 2025	Quiz Lesson-4: Quiz (graded)	due by 8am
Wed Feb 5, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Feb 6, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Feb 10, 2025	Quiz Lesson-5: Quiz (graded)	due by 8am
Wed Feb 12, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Feb 13, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Feb 17, 2025	Quiz Lesson-6: Quiz (graded)	due by 8am
	Assignment Module Two: Project	due by 8am
Wed Feb 19, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Feb 20, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Feb 24, 2025	Quiz Lesson-7: Quiz (graded)	due by 8am

Date	Details	Due
Wed Feb 26, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Feb 27, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Mar 3, 2025	Quiz Lesson-8: Quiz (graded)	due by 8am
Wed Mar 5, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Mar 6, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Mar 10, 2025	Quiz Lesson-9: Quiz (graded)	due by 8am
	Assignment Module Three: Project	due by 8am
Wed Mar 12, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Mar 13, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Mar 17, 2025	Quiz Lesson-10: Quiz (graded)	due by 8am
Wed Mar 19, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am

Date	Details	Due
Thu Mar 20, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Wed Mar 26, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Mar 27, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Fri Mar 28, 2025	Quiz Lesson-11: Quiz (graded)	due by 8am
Mon Mar 31, 2025	Quiz Lesson-12: Quiz (graded)	due by 8am
	Assignment Module Four: Project	due by 8am
Wed Apr 2, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Apr 3, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Apr 7, 2025	Quiz Lesson-13: Quiz (graded)	due by 8am
Wed Apr 9, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Apr 10, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am

Date	Details	Due
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Apr 14, 2025	Quiz Lesson-14: Quiz (graded)	due by 8am
Wed Apr 16, 2025	Calendar Event CS 7280 Office Hour: Burak Gurbuz	10am to 11am
Thu Apr 17, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am
	Calendar Event CS 7280 Office Hour : Jake Pichelmeyer, PhD	10am to 11am
Mon Apr 21, 2025	Assignment Module Five: Project	due by 8am
Thu Apr 24, 2025	Calendar Event CS 7280 Office Hour: Vivian Tran	8am to 9am