

# C S 5483 – Network Science

## Fall 2022

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<b>Instructor</b>	Dr. Sridhar Radhakrishnan (sridhar@ou.edu)
<b>Office Hours</b>	Tuesday 4:00 PM – 5:00 PM <a href="https://oklahoma.zoom.us/j/98843167956?pwd=SmhLUjNtcGhadU84TUN3WlpJbW4vdz09">https://oklahoma.zoom.us/j/98843167956?pwd=SmhLUjNtcGhadU84TUN3WlpJbW4vdz09</a>
<b>Course Timings</b>	Online; There will be announced Tuesday classes from 5:00 PM – 6:30 PM; This is reviews; Project Proposal presentation; and other presentations. <a href="https://oklahoma.zoom.us/j/98217039247?pwd=U0tjSHJFQ0hhMWdqNkFYNVdsTTRtQT09">https://oklahoma.zoom.us/j/98217039247?pwd=U0tjSHJFQ0hhMWdqNkFYNVdsTTRtQT09</a>
<b>Course Location</b>	On Canvas
<b>Course Prerequisite</b>	CS/DSA 4413 or permission of the instructor
<b>Course Objectives</b>	Topics to be covered include fundamental algorithms for network analysis, investigating properties of networks, learning community detection methods, understanding network inference methods, understanding dynamics of networks, percolation, resilience, spreading phenomenon, social influence, and cascades. A variety of application contexts will be used, including physical, informational, biological, cognitive, and social systems.
<b>Useful Course Material</b>	<ol style="list-style-type: none"><li>1. <i>Networks</i>: Book by <i>Mark Newman</i>, 2<sup>nd</sup> Edition, Oxford University Press, 2021, ISBN-13: 978-0123850591, ISBN-10: 0123850592</li><li>2. <i>Social Media Mining: An Introduction</i>, Cambridge University Press New York, NY, USA ©2014 ISBN:1107018854 9781107018853</li><li>3. Material that will be placed on canvas.</li></ol>
<b>Course Requirements</b>	Students will be required to take several quizzes. In addition, there will a set of homework assignments some of which will involve programming exercises with Python and NetworkX library. There will be an individual final project and a presentation. Failure to complete the final project and the presentation will result in an automatic F as the overall course grade.

## Course Grading

The course letter grade will be assigned based on the overall percentage: 90-100 (A), 80-89 (B), 70-79 (C), 60-69 (D), and < 60 (F). The allocation of percentages is given below:

	Grade Distribution
Quizzes	20%
Python Programming Assignments	25%
Homework Assignments	20%
Final Project – Proposal (5%), Progress Reports (5%), Demonstration (10%)	20%
Presentation	10%
Participation on all project presentations	5%

## Final Project and Milestones

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There are several ways in which this course project can be completed:

- (1) Development of software to perform network analysis or modeling on very large networks.
- (2) Reproduce some results of a paper based on different data or different methods.

All projects must involve some sort of visualization. Here are the due dates. The evaluation percentages are also provided below.

October 3: project proposal  
October 31: progress report-1  
November 14: progress report-2  
November 28: project demonstrations  
December 5: project presentations

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## Lecture Notes and Attendance

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It is advised that students listen all lectures.

## Tentative Lecture Schedule

Week of Date	Topics
8/22/22	Module 0: About this course Module 1: Introduction to Network Science, Programming with Python and NetworkX
8/29/22	Module 2: Technological, Information, Social, and Biological Networks
9/5/22	Module 2 (contd.): Technological, Information, Social, and Biological Networks Module 3: Fundamentals of Network Theory: Mathematics of Networks
9/12/22	Module 3 (contd.): Fundamentals of Network Theory: Mathematics of Networks Module 4: Fundamentals of Network Theory: Measures and Metrics
9/19/22	Module 4 (contd.): Fundamentals of Network Theory: Measures and Metrics Module 5: Fundamentals of Network Theory: Graph Algorithms
9/26/22	Module 6: Fundamentals of Network Theory: Network Statistics and Measurement Error Module 7: Fundamentals of Network Theory: The Structure of Real-World Networks
10/3/22	Module 8: Network Models: Random Graphs
10/10/22	Module 9: Network Models: The Configuration Model
10/17/22	Module 10: Network Models: Models of Network Formation
10/24/22	Module 11: Applications: Community Structure
10/31/22	Module 12: Graph Databases Module 13: Graph Neural Net
11/7/22	Module 14: Applications: Percolation and Network Resilience
11/14/22	Module 15: Applications: Epidemics on Networks
11/21/22	<b>Thanksgiving Break</b>
11/28/22	Module 16: Advanced Topics
On December 6 2022	Final Project Demonstration and Presentations

## **Module 0: About this course**

- 0.1 Introducing your Professor
  - a. Professor
  - b. Contact Information
- 0.2 Course Contents
  - a. About network science
  - b. Textbooks used
  - c. Topics to be covered
- 0.3 Course tools
  - a. Python – GitHub, Jupyter, NetworkX, and visualization tools
- 0.4 Grading Policies
- 0.5 How to learn online

## **Module 1: Introduction to Network Science, Programming with Python and Network X**

- 1.1 Networks Definition and Examples
  - d. What are networks? Nodes (vertices) and links (edges), directed, undirected
  - e. Examples of various networks along with their sizes
- 1.2 Networks Classification and the Information it Conveys
  - a. Classification of the types of networks: technology, information, social, and biological
  - b. What can we learn from networks?
- 1.3 Properties of networks
  - a. Degree, in-degree, out-degree, hubs, distance, radius, diameter, small-world effect (degrees of separation), clusters, communities
- 1.4 Python
  - a. Python notebook, NetworkX, Simple visualization

## **Module 2: Technological, Information, Social, and Biological Networks**

- 2.1 Technological Networks
  - a. The Internet – How is it organized? How can we get its structure using TRACEROUTE? What are routing tables? How can be it used to understand the structure of the Internet?
  - b. The Telephone Network: Circuit-Switched Network and Packet-Switched Networks
  - c. Power Grids: How are they modeled? What are smart Grids?
  - d. Transportation Networks: Modeling – Road network and train network
  - e. Delivery and Distribution Networks
  - f. Interdependent Networks
- 2.2 Information Networks
  - a. The world wide web: A directed network
  - b. Using a crawler to get WWW's structure: wget, Nutch, GRUB, and Sphinx
  - c. Citation Networks, Peer-to-Peer Networks, Recommender Networks, and Keyword indexes
  - d. Drug-drug interaction network
- 2.3 Social Networks
  - c. Empirical study of social networks
  - d. Constructing social networks: interviews and questionnaire, ego-centric networks, direct observation, archival data
  - e. Affiliation networks
  - f. Small-World Experiment
  - g. Snowball sampling, contact tracing, and random walks
- 2.4 Biological Networks
  - a. Metabolic networks, protein-protein interaction network, genetic regulatory networks

- b. Networks in the Brain – Networks of neurons, networks of functional connectivity in the brain
  - c. Ecological networks: Food webs, Host-parasite networks, Mutualistic networks
- 2.5 Python
- a. Downloading various types of networks and visualizing with python and graphViz

<b>Module 3: Fundamentals of Network Theory: Mathematics of Networks</b>
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- 3.1 Networks and their representations:
  - a. Edge list, Adjacency Matrix, Adjacency List, Weighted Networks, Sparse vs Dense Graph
- 3.2 Varieties of graphs
  - a. Directed and Acyclic
  - b. Bipartite, Hypergraphs
  - c. Trees
  - d. Planar
  - e. Multilayer and Dynamic
- 3.3. Properties of Graphs: degree, density, sparsity, walks, paths, shortest paths, diameter
  - a. Degree, average degree, and moments
  - b. Density and Sparsity
  - c. Paths: walks, shortest paths, and diameter
  - d. Components: connected components, strongly connected components
- 3.3 Independent Paths, connectivity, cut sets, max flow, min cut
  - a. Vertex and edge disjoint paths
  - b. Connectivity: bi-connectivity and k-connectivity
  - c. Cut sets and relationship to connectivity, max flow and min cut on weighted networks
- 3.4 Graph Laplacian
  - a. Definition and properties
  - b. Graph Partitioning definition
  - c. Network Visualization
  - d. Random walks
  - e. Resistor networks
- 3.5 Python
  - a. Take a graph and show how the various properties, paths, cuts, connectivity, and graph Laplacian can be calculated

<b>Module 4: Fundamentals of Network Theory: Measures and Metrics</b>
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- 4.1 Centrality
  - a. Degree Centrality
  - b. Eigenvector Centrality
  - c. Katz Centrality
  - d. Page Rank
  - e. Hubs and Authorities
  - f. Closeness Centrality
  - g. Betweenness Centrality
- 4.2 Groups of Nodes
  - a. Cliques
  - b. Components and K-Components
- 4.3 Transitivity
  - a. Clustering Coefficient
  - b. Reciprocity
- 4.4 Signed Edges and Structural Balance

- 4.5 Similarity
  - a. Structural Equivalence
  - b. Regular Equivalence
- 4.6 Homophily and Assortative Mixing
  - a. Assortative Mixing by unordered characteristics
  - b. Assortative Mixing by ordered characteristics
- 4.7 Python
  - a. Take a graph's adjacency matrix and calculate various centrality measures
  - b. Write a python code to determine a k-clique in a graph

#### **Module 5: Fundamentals of Network Theory: Graph Algorithms**

- 5.1 Running time and computational complexity
- 5.2 Representation of Networks: Edge List, Adjacency Matrix, Adjacency List
- 5.3 Depth First Search Algorithm: Finding Connected Components
- 5.4 Breadth First Search: Counting Triangles and Finding Diameter of a network
- 5.5 Single Source Shortest path algorithm – Dijkstra's
- 5.6 All-Pair Shortest path algorithm – Floyd's algorithm: Betweenness Centrality
- 5.7 Max-Flow and Min-Cut
- 5.8 K-disjoint paths algorithm
- 5.9 Finding maximal cliques in a graph
- 5.10 Python
  - a. Using the NetworkX library and sample random graphs, determine compute the number of connected components in a graph.

#### **Module 6: Fundamentals of Network Theory: Network Statistics and Measurement Error**

- 6.1 Types and Sources of Errors
- 6.2 Estimating Errors: Statistical, Maximal Likelihood, Expectation Maximization Algorithm
- 6.3 Correcting Errors: Link Prediction, Node Disambiguation
- 6.4 Python
  - a. Implement a link prediction algorithm using Python and NetworkX

#### **Module 7: Fundamentals of Network Theory: The Structure of Real-World Networks**

- 7.1 Real-World Networks and Features
- 7.2 Degree Distributions
- 7.3 Power laws and scale-free networks, Detecting and Visualizing power-laws
- 7.4 Distribution of Centrality measures
- 7.5 Clustering Coefficients
- 7.6 Assortative Mixing
- 7.7 Python
  - a. Take a set of real-world graphs and show its degree distributions

#### **Module 8: Network Models: Random Graphs**

- 8.1 Random Graphs
- 8.2 Mean Number of Edges and Mean Degree
- 8.3 Degree Distribution
- 8.4 Clustering Coefficient
- 8.5 Giant Component
- 8.6 Small Components
- 8.7 Path Lengths
- 8.8 Issues with Random Graphs
- 8.9 Python
  - a. Write a program to generate various type of random graphs

## **Module 9: Network Models: The Configuration Model**

- 9.1 The configuration model: Edge probability and Expected degree
- 9.2 Excess Degree distribution
- 9.3 Clustering Coefficient
- 9.4 Tree-Like Networks
- 9.5 Number of second neighbors of a node
- 9.6 Giant, Small Components, and Diameter
- 9.7 Python
  - a. Take a large graph, run connected components algorithm, show the giant component by removing edges at random.

## **Module 10: Network Models: Models of Network Formation**

- 10.1 Preferential Attachment – Price Model
- 10.2 Barabasi and Albert Model
- 10.3 Node-copying Model
- 10.4 Python
  - a. Implement the preferential attachment model.

## **Module 11: Applications: Community Structure**

- 11.1 Dividing Networks into groups
- 11.2 Modularity Maximization: Louvain Algorithm
- 11.3 Kernighan-Lin Algorithm
- 11.4 Spectral Partitioning
- 11.5 Other Community Detection Algorithms: Betweenness, Hierarchical Clustering,
- 11.6 Measuring Performance of Community Detection Algorithms
- 11.7 Python
  - a. Implement and execute the Louvain algorithm on a chosen network

## **Module 12: Graph Databases**

- 12.1 Relational Database System
- 12.2 Introduction to Graph Database
- 12.3 Queries on Graph Databases
- 12.4 Introduction to Neo4j, Amazon Neptune and Graph Studio by Oracle
- 12.5 Real-world use cases

## **Module 13: Graph Neural Networks**

- 13.1 Introduction to Neural Networks
- 13.2 Graph Convolution Network
- 13.3 Applications of GNNs
- 13.4 Introduction to PyTorch and PyGeometry

## **Module 14: Applications: Percolation and Network Resilience**

- 14.1 Percolation
- 14.2 Uniform Removal of Nodes
- 14.3 Percolation in Real-World Networks
- 14.4 Algorithm for Percolation
- 14.5 Python
  - a. Implement and execute the percolation algorithm discussed

## **Module 15: Applications: Epidemics on Networks**

- 15.1 Models of Spread of Infection
- 15.2 SI Model
- 15.3 SIR Model
- 15.4 SIS Model
- 15.5 SIRS Model
- 15.6 Outbreak Sizes and Percolation
- 15.7 Python
  - a. Implement and execute SI and SIR model on a random network

## **Module 16: Advanced Topics**

- 16.1 Time-Evolving Network Structures and Algorithms
- 16.2 Interdependent Networks, Resilience, and Restoration
- 16.3 Dynamics of Brain Networks
- 16.4 Financial Markets Meets Network Science

### **Student Evaluations:**

The College of Engineering utilizes student ratings as one of the bases for evaluating the teaching effectiveness of each of its faculty members. The results of these forms are important data used in the process of awarding tenure, making promotions, and giving salary increases. In addition, the faculty uses these forms to improve their own teaching effectiveness. The original request for the use of these forms came from students, and it is students who eventually benefit most from their use. Please take this task seriously and respond as honestly and precisely as possible, both to the machine-scored items and to the open-ended questions.

### **University Policies:**

In this section, include the mandatory University policies.

#### **University Mandatory Masking Policy**

“Each OU campus has implemented and will enforce a policy mandating that masks be worn by employees, students, patients, and visitors (1) when they are inside University facilities and vehicles and (2) when they are outdoors on campus and social distancing of at least six feet is not possible. 1 Each campus policy has been reviewed and approved by OU’s Chief COVID Officer 2 and is effective until further notice.” (<https://www.ou.edu/coronavirus/masking-policy>)

#### **Canvas Learning Management System** <https://canvas.ou.edu>

Log in with your OUNetID (usually the first 4 letters of your last name followed by a 4-digit number). All assignments, deadlines, grades, announcements, and course documents will be posted to the CS 5483 Canvas page. It is your responsibility to regularly check for updates. (You can configure Canvas to email you notifications.)

#### **Academic Integrity**

Cheating is strictly prohibited at the University of Oklahoma, because it devalues the degree you are working hard to get. As a member of the OU community, it is your responsibility to protect your educational investment by knowing and following the rules. A student must complete his/her tests, projects and assignments on his/her own. A student's signature on any tests, projects and assignments indicates that the student neither gave nor received unauthorized aid. Academic misconduct is defined as any act which improperly affects the evaluation of a student's academic performance or achievement. It specifically includes cheating, plagiarism, fabrication, fraud, destruction of property, and bribery or intimidation, as well as assisting others or attempting to engage in such acts. It is the responsibility of each student to be familiar with the definitions, policies



and procedures concerning academic misconduct. For more information, please review the Student's Guide to Academic Integrity at [http://integrity.ou.edu/students\\_guide.html](http://integrity.ou.edu/students_guide.html).

**Incomplete Grades:** A letter grade of I (incomplete) is intended for the rare circumstance when a student, who has been successful in class, has an unexpected event occur shortly before the end of the semester. I generally will not consider giving an incomplete grade unless three conditions are met:

1. It is close to the end of the semester.
2. You have a grade of C or better in the class.
3. The reason you are unable to complete the class is compelling.

### **Religious Observance**

It is the policy of the University to excuse the absences of students that result from religious observances and to reschedule examinations and additional required classwork that may fall on religious holidays, without penalty.

### **Reasonable Accommodation Policy**

The Accessibility and Disability Resource Center is committed to supporting students with disabilities to ensure that they are able to enjoy equal access to all components of their education. This includes your academics, housing, and community events. If you are experiencing a disability, a mental/medical health condition that has a significant impact on one or more life functions, you can receive accommodations to provide equal access. Possible disabilities include, but are not limited to, learning disabilities, AD(H)D, mental health, and chronic health. Additionally, we support students with temporary medical conditions (broken wrist, shoulder surgery, etc.) and pregnancy. To discuss potential accommodations, please contact the ADRC at 730 College Avenue, (ph.) 405.325.3852, or [adrc@ou.edu](mailto:adrc@ou.edu).

### **Title IX Resources and Reporting Requirement**

Anyone who has been impacted by gender-based violence, including dating violence, domestic violence, stalking, harassment, and sexual assault, deserves access to resources so that they are supported personally and academically. The University of Oklahoma is committed to offering resources to those impacted, including: speaking with someone confidentially about your options, medical attention, counseling, reporting, academic support, and safety plans. If you would like to speak with someone confidentially, please contact [OU Advocates](#) (available 24/7 at 405-615-0013) or another confidential resource (see "[Can I make an anonymous report?](#)"). You may also choose to report gender-based violence and discrimination through other means, including by contacting the [Institutional Equity Office](#) ([ieo@ou.edu](mailto:ieo@ou.edu), 405-325-3546) or police (911). Because the University of Oklahoma is committed to the safety of you and other students, I, as well as other faculty, Graduate Assistants, and Teaching Assistants, are mandatory reporters. This means that we are obligated to report gender-based violence that has been disclosed to us to the Institutional Equity Office. This includes disclosures that occur in: class discussion, writing assignments, discussion boards, emails and during Student/Office Hours. For more information, please visit the [Institutional Equity Office](#).

### **Adjustments for Pregnancy/Childbirth Related Issues**

Should you need modifications or adjustments to your course requirements because of documented pregnancy-related or childbirth-related issues, please contact your professor or the Accessibility and Disability Resource Center at 405/325-3852 as soon as possible. Also, see the Institutional Equity Office [FAQ on Pregnant and Parenting Students' Rights](#) for answers to commonly asked questions.

### **Final Exam Preparation Period**

Pre-finals week will be defined as the seven calendar days before the first day of finals. Faculty may cover new course material throughout this week. For specific provisions of the policy please refer to OU's [Final Exam Preparation Period policy](#).

### **Emergency Protocol**

During an emergency, there are official university [procedures](#) that will maximize your safety.

**Severe Weather:** If you receive an OU Alert to seek refuge or hear a tornado siren that signals severe weather.

1. Look for severe weather refuge location maps located inside most OU buildings near the entrances
2. Seek refuge inside a building. Do not leave one building to seek shelter in another building that you deem safer. If outside, get into the nearest building.
3. Go to the building's severe weather refuge location. If you do not know where that is, go to the lowest level possible and seek refuge in an innermost room. Avoid outside doors and windows.
4. Get in, Get Down, Cover Up
5. Wait for official notice to resume normal activities.

Additional [Weather Safety Information](#) is available through the Department of Campus Safety.

**Armed Subject/Campus Intruder:** If you receive an OU Alert to shelter-in-place due to an active shooter or armed intruder situation or you hear what you perceive to be gunshots:

1. *Avoid:* If you believe you can get out of the area WITHOUT encountering the armed individual, move quickly towards the nearest building exit, move away from the building, and call 911. 2. *Deny:* If you cannot flee, move to an area that can be locked or barricaded, turn off lights, silence devices, spread out, and formulate a plan of attack if the shooter enters the room. 3. *Defend:* As a last resort fight to defend yourself.

For more information, visit [OU's Emergency Preparedness site](#).

[Shots Fired on Campus Procedure – Video](#)

**Fire Alarm/General Emergency:** If you receive an OU Alert that there is danger inside or near the building, or the fire alarm inside the building activates: 1. *LEAVE* the building. Do not use the elevators. 2. *KNOW* at least two building exits 3. *ASSIST* those that may need help 4. *PROCEED* to the emergency assembly area 5 *ONCE safely outside, NOTIFY first responders of anyone that may still be inside building due to mobility issues.* 6. *WAIT* for official notice before attempting to re-enter the building.

[OU Fire Safety on Campus](#)

**Mental Health Support Services:** If you are experiencing any mental health issues that are impacting your academic performance, counseling is available at the University Counseling Center (UCC). The Center is located on the second floor of the Goddard Health Center, at 620 Elm Rm. 201, Norman, OK 73019. To schedule an appointment call (405) 325-2911. For more information, please visit [University Counseling Center](#).

*\*Every part of this syllabus is subject to adjustment as the semester progresses. If you are dissatisfied with the course policies, grading, and assignments, please contact the instructor. Reasonable requests for modifications may be accommodated at the instructor's discretion.*