National Cheng Kung University
Modular Course 2024 Summer Program

領域：自然與工程科學

複雜系統中的網路結構、模型和特性
Network structure, modeling, and properties for complex systems

Instructor	Affiliation	Graduation (Ph.d.)
朱書賢	Intel Corporation, Hillsboro, OR	College of Science and Engineering, University of Minnesota-Twin Cities, Minneapolis, MN

Course Type	Course Credit	Student Size (Maximum)
Lecture + Recitation	1.5	25

Student Background

College of Science、Institute of Technology、College of Biological Sciences and Technology、College of Electrical Engineering and Computer Science、Faculty of Management、College and Faculty of Medicine、College of Planning and Design、College of Social Science

Difficulty

☐ Challenging ■Moderately Difficult ☐ Medium ☐ Entry Level (Basic)

Format of The Course

Lecture 70%，Practice 23%、Report7%

Lectures will be provided in the morning and lab sessions are in the afternoon. Knowledge of python is not required and understanding of basic programming logic will help. During the first part of lab sessions, we will go over examples and python homework questions. Source code will be provided so that students can follow the code in the class and practice after class. The second part of lab sessions are offered as TA hour for questions from homework and project. Students can work on them during this period of time as well.

Grading Policy

Quiz 28%、Homework 40%、Project 32%

- Quiz 28%:：

  Quizzes will be given at the beginning (9:00-9:30) of lectures from day 2 to day 5. Quiz questions cover the previous lecture.
- Homework 40%：

  Homework will be hand out during the first four lectures and due by the end of the next lecture.
- Project 32%：

  Each group can have no more than four members who shall work on an assigned network problem, explore possible solutions, and share discussion and results. Reports are individual, especially for the following parts: problem description, analysis, discussion, and conclusion. Problems will be given from a single aspect, however, they usually can be better described from multiple perspectives. Therefore, the problem description should be composed based on all your understanding instead of just copying the problem statement from the instructor. Analysis, discussion, and conclusion should be presented based on individual opinions and focuses due to the fact that combinations of metrics/properties/characteristics widely expand the variety of reasoning, explanation, and meaning. Group discussion may be taken as a reference to derive from, and group members

are open to sharing data, solutions, code, and computational results. Everyone is expected to hand in a report in 2 days after the end of this course. The report should include title, author, abstract, introduction, problem statement, method, result, discussion, conclusion, and references. The report can be written in either English or Chinese.

Code of Conduct for The Course

Go to class on time and submit homework (reports) on time

Course Description

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, structural properties, evolution dynamics, and vulnerabilities of such complex networks, aiming to better understand the variant and invariant properties, such as patterns of connection, interaction, and relationships, of the underlying system. Applications of network science span a wide variety of areas that pervade our lives: internet, neuroscience, power grid, physical, biological, ecology, and social systems. This course will focus on essential concepts and core ideas of network literacy and introduce tools to analyze and visualize networks.

Keywords：Network Characteristics, Random Network, Real Network, Scale-Free Network, Small-World Network

Timetable and Syllabus

Period	Timetable	Syllabus
8/5(MON)	09:00-12:00	(a) Course Introduction We first cover course specifics and logistics. We then introduce the notion of network and present a general notion of Network Science as a cross-disciplinary field. We will motivate this via several examples and highlight the associated challenges. (b) Introduction to Graph Theory We will cover basic notions and definitions related to undirected and directed graphs: vertices, edges, simple graphs, weighted graphs, neighborhoods, degree, path, cycle, connected components, random walks, directed acyclic graphs, bipartite graphs, max-flow/min-cut, etc. Also, we introduce matrix network representations, such as adjacency, incidence, and Laplacian matrices.
	13:00-15:30	(a) Lab: Python introduction and installation; Network creation and visualization with adjacency, incidence, and Laplacian matrices.
8/6(TUE)	09:00-12:00	(a) Random, Real, and Scale Free Networks • Network properties: degree distribution, clustering coefficients, path length, diameter, connectivity

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		• Properties of real networks • Erdos-Renyi random graph model
	13:00-15:30	(b) Lab: Compute network properties of a given network; Generate and visualize Erdos-Renyi random networks and review their properties
8/7(WED)	09:00-12:00	(a) Random, Real, and Scale Free Networks • Watts-Strogatz (small-world) model • Kronecker graph model • Scale-free networks and preferential attachment algorithm • Assortative vs disassortative networks
	13:00-15:30	(b) Lab:Generate and visualize small-world networks, Kronecker networks, and scale-free networks, and review their properties
8/8(THU)	09:00-12:00	(a) Centrality and Network-core Metrics We introduce the notion of node centrality as a way to measure the importance of a node within the network. We compare classical measures such as degree, closeness, betweenness, eigenvector, and Katz centrality. We then continue with the following centrality metrics： • Link-based centrality metrics • Path-based centrality metrics • k-core decomposition • Core-periphery structure • Rich-club set of nodes
	13:00-15:30	(b) Lab: Compute and compare centrality measures of previously generated networks and real network examples
8/9(FRI)	09:00-12:00	(a) Network Structures: Subnetwork, motifs, and graphlets (b) The Small-World Phenomenon
	13:00-15:30	(c) Lab: Project presentation

Goal of the Course

1. Explain basic metrics and measures used to characterize networks
2.Analyze a network using various measures with a suitable network analysis software tool
3. Discuss the strengths and weaknesses of random graph models
4. Apply algorithms for node ranking, community detection, and network comparison
5. Understand the interdisciplinary nature of the area of network science

The Importance, Cross-Over Disciplinary and Contemporary of The Curriculum

Network science, a rapidly developing area, provides systematic computational methods for studying network topology, structural properties, evolution dynamics, and vulnerabilities. Nowadays, with the dramatic increase of computing capability, researchers have applied network science to a wide variety of areas for better understanding the property of systems around us. This mathematics, engineering, and computer sciences

interdisciplinary course will introduce network formations and properties, demonstrate real-world network systems, guide students through computational practices, and eventually deliver students a computer-aided research experience.

Remarks

Prerequisites：No requirement. Basic knowledge on Graph Theory, Probability Theory, Linear Algebra, and Python will be helpful.

Software and Tools:

1. Python: https://www.python.org/downloads/
2. NetworkX: https://networkx.org/documentation/stable/reference/index.html
3. igraph: https://igraph.org/python/
4. RolX: https://github.com/benedekrozemberczki/RolX
5. BCTPy: https://pypi.org/project/bctpy
6. Graphviz: https://pypi.org/project/graphviz/

Reference：

A. Barabasi, Network Science http://networksciencebook.com/

Other References：

1. E.J. Newman, Networks: An Introduction, Oxford University Press, 2010. https://oxford.universitypressscholarship.com/view/10.1093/acprof:oso/9780199206650.001.0001/acprof-9780199206650
2. D. Easley and J. Kleinberg, Networks, Crowds and Markets, Cambridge Univ Press, 2010. https://www.cs.cornell.edu/home/kleinber/networks-book/

本課程若因天災等不可抗力之因素或中央、地方政府公告停課，授課教師需依情況依建議補課方式調整課程進度與補課；若需使用假日、國定假日補課，則需與所有修課學生達成共識方能用例假日補課。

建議補課方式：

1. 線上授課方式補課；
2. 當預期可能會因天災(颱風、超大豪雨…等)宣佈停課時，建議老師先行調整加快課程進度或預先增加可能天氣預警之前幾次課程時數；
3. 停課後隔天起延後下課，補足停課延誤的進度；若停課超過 1 天，則在開始上課後延後下課補課，或當週星期六、日補課；

更改課程授課方式，例如：DEMO 改以考試、報告、作業取代。