This course introduces the emerging discipline of network science, including the study of complex networks and their applications. We immerse students in a variety of networks, demonstrating and practicing techniques and models enabling insight into situations whose essence is best understood by networks, leading to greater awareness and even prediction. The topics discussed build from graph-theoretic concepts, and will address the mathematics of networks, network applications, and research applicability. We will expose students to the building blocks of network analysis, learn about the ongoing research in the field through presentations and research articles, and apply gained knowledge to the analysis of real and synthetic networks.

Complex networks – upon which we will focus throughout this course – are networks that feature patterns of connection between their elements that are neither purely regular nor purely random. Such networks have gained increasing attention in recent years from those seeking to understand emerging phenomena in technology and society. Some examples of complex networks are on-line social networks, the Internet, the World Wide Web, neural networks, food-webs, metabolic networks, power grids, airline networks, national highway networks, the brain, and many more. We will study models created for these networks, beginning with random networks and followed by more sophisticated models of network formation: scale-free networks, small-world networks, and preferential attachment. We conclude with selective topics from the study of their properties such as networks’ degree distributions (Poisson vs. power law), centralities, shortest paths, clustering, robustness (resilience versus random attacks), and community detection, followed by ideas in new areas of current research.

Participants should have a doctoral degree in a quantitative science. Otherwise, at least a course in discrete mathematics and linear algebra is needed. Senior PhD students are also welcome.
Lieutenant Colonel Jonathan W. Roginski (Jon) is the Director of the West Point Network Science Center, a research organization that annually manages approximately $1M of reimbursable research supporting a diverse portfolio of United States Department of Defense decision makers. He is also an Assistant Professor of Mathematical Sciences at the United States Military Academy at West Point, Course Director for both the Academy’s Fundamentals of Network Science and Linear Algebra courses, and the program manager for the Academy’s Network Science minor. His research interests build from the experience of using quantitative and qualitative data science methods to assess the operational progress of military units against their goals in combat and home station, supporting the 10th Mountain Division (Light Infantry). This service highlighted the quality of irreducibility in military problem solving and the necessity of methods that “embraced the complexity” of the modern world, rather than assuming it away. Jon’s personal research leverages the implications of graph comparison techniques toward Department of Defense decision making in attack, defense, and stability scenarios by accounting for operational complexity through network modeling. He is also invested in cultivating the future of decision support technicians and is active in the mentorship of junior operations research analysts. Jon is a part of the Networks in Classroom Education (NiCE) team, using network science to improve curriculum development and delivery in classrooms at all pre-collegiate levels. Jon is a member of several professional societies and active in professional service, including chairing conference program committees, organizing workshops, serving as a reviewer for journals and grants.

Dr. Raluca Gera joined the Naval Postgraduate School in 2005, where she is now a tenured Associate Professor. She is also a researcher in the Center for Cyber Warfare at the Naval Postgraduate School, as well as an associate researcher in the Network Science Center at United States Military Academy. Her research interests are in graph theory and complex networks, with applications to the study of the Internet, Cyber networks and Natural Language Processing, sponsored by multiple DoD organizations. Dr. Gera is the founder and director of the Academic Certificate in Network Science, a program that has graduated 46 students in its short 4 year life. She is the co-founder of the Golden Section NExT (NorCal, HI and NV), holding an active role in its current leadership, along with Young Mathematician’s Network and Graph Theory Notes of NY, and Bay Area Discrete Math. Her latest passion is network science education of the young generation through teaching short courses for professors and organizing workshops (such as the Networks in Classroom Education (NiCE) for Kindergarten teachers and above). She has published over 50 journal and conference papers and 1 edited books. She is active in professional service, including chairing conference program committees, organizing workshops, serving as journal editors, and Erdos Number is 2.
~ Learning Objectives ~

Our goals for you, the participant, in this class are twofold. First, you will develop the mathematical sophistication needed to understand properties of complex networks. Second, armed with this understanding you will be able to identify and apply appropriate methodologies and techniques to answer questions using network thinking and analysis. In doing this, you will

1. Analyze new networks using the main concepts of complex network analysis:
   - identify network models and explain their structures;
   - choose between several methodologies in analyzing networks;
   - be able to grasp the meaning of a new research paper in complex networks;

2. Evaluate networks:
   - contrast network models to explain emergent features of complex networks;
   - synthesize the new research work in this evolving area;
   - critique peer’s research;

3. Create new network research:
   - design new network models building on the existing ones and available data;
   - design experiments to test hypothesis based on data to be analyzed;
   - generate new theory by expanding on the designed experiments.

~ Learning Outcomes ~

At the end of the course, participants should be able to:

- Understand how to use network science concepts,
- Perform network science modeling based on real data, and
- Select correct methodologies needed to identify how to use knowledge on these complex networks to produce a research article or apply it in a real world situation.

The learning outcomes above are achieved through building and analyzing network profile summaries, reading scientific papers and writing technical research articles. This gives participants the mathematical sophistication and confidence to use gained network science experience as situations arise.
~ Course Fees ~

- SGD856.00 per pax (incl. GST) for Ph.D. students
- SGD1,284.00 per pax (incl. GST) for Public

~ Sessions ~

**Day 1**
Introduction to Network Science
- Networks are Everywhere
- Synthetic Networks as Models
- The Network Profile Summary
- Research Project Goals

Applying Network Science
- Seminal Research
- Network Lab Experience: Software Introduction and Exercise

**Day 2**
Exploring the Network “Landscape”
- Degree Distribution
- Power Law
- Clustering
- Node Similarity
- Assortativity / Homophily

Network Lab Experience: Describing a Network

**Day 3**
Community Detection
- Community Detection Algorithms
- Generating Networks Preserving Community Structure
- Core-Periphery Structure

Network Lab Experience: Community Detection

**Day 4**
Measures of “Importance:” Centralities
- Closeness and Eigenvector
- Katz and PageRank
- Betweenness

Network Lab Experience: Centralities

For more information, please contact Stephanie Teo at email: tdsteomw@nus.edu.sg or Tel: 6516-3497. Thank you.