# Network Science (NETS)

## Courses

**NETS 1990. Elective. (1-4 Hours)**
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

**NETS 2990. Elective. (1-4 Hours)**
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

**NETS 3990. Elective. (1-4 Hours)**
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

**NETS 4990. Elective. (1-4 Hours)**
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

**NETS 5050. Fundamentals of Complex Networks. (4 Hours)**
Presents an interdisciplinary introduction to the science of complex networks and the starting point for students looking to develop an expertise in network science. Explores the mathematical foundation of networks (graph theory) and examines common tools for describing and analyzing networks. Discovers the origin of complex networks throughout our world, examining properties such as the degree distribution, centrality measures, path lengths, clustering, homophily, and robustness. Investigates evolving networks, growing networks, and network null models. Introduces common applications of network science in a variety of domains including biology, medicine, sociology, technology, and finance. Requires students to conduct their own analysis of a real network dataset of their choosing as part of the final project.

**NETS 5051. Analyzing Complex Network Data. (4 Hours)**
Presents an overview of the core data scientific skills required to analyze complex networks.Through hands-on lectures, labs, and projects, exercises actionable skills about network analysis techniques using Python (in particular, the NetworkX library). Covers the basics of network analysis including data input/output, network statistics, and visualization.Explores instruction in random graph models and algorithms for computing network properties such as path lengths, clustering, degree distributions, and community structure. Offers students an opportunity to develop web scraping skills and introduces the vast landscape of software tools for analyzing complex networks. Concludes with a large-scale final project to demonstrate proficiency in network analysis.

**NETS 5052. Advanced Tools for Complex Network Analysis. (4 Hours)**
Delves into more advanced techniques for analyzing large, complex networks such as filtering, backboning, and embedding. Demonstrates how the presence of extra network features, such as a temporal dimension, requires more advanced and computationally demanding techniques. Presents a more formal treatment of network generative models, such as the stochastic block model; exponential random graphs with particular focus on sampling from such models; and the basics of network reconstruction involving appropriate statistical/inference methods.

**Prerequisite(s):** NETS 5051 with a minimum grade of C

**NETS 5116. Network Science 1. (4 Hours)**
Introduces network science and the set of analytical, numerical, and modeling tools used to understand complex networks emerging in nature and technology. Focuses on the empirical study of real networks, with examples coming from biology (metabolic, protein interaction networks), computer science (World Wide Web, Internet), or social systems (e-mail, friendship networks). Shows the organizing principles that govern the emergence of networks and the set of tools necessary to characterize and model them. Covers elements of graph theory, statistical physics, biology, and social science as they pertain to the understanding of complex systems.

**Prerequisite(s):** PHYS 2303 with a minimum grade of D- or graduate program admission
**Attribute(s):** NUpath Natural/Designed World

**NETS 5126. Spreading on Networks: From Epidemics to Memes. (4 Hours)**
Explores fundamentals of contagion on networks, starting with simple disease dynamics in mean field systems and building to spreading processes on complex networks. Examines a variety of contagion modeling techniques, which include state-of-the-art techniques for using networks to forecast the trajectory of an infectious disease, the emergence of a best-seller, predicting elections, or even modeling cascading failures in infrastructure networks. Introduces a diverse range of datasets and case studies, which students may draw from for their final modeling/analysis project. From biological pathogens like SARS-CoV-2, Ebola, and influenza to social contagions like fake news, memes, and influencers, complex network analysis gives us powerful tools to understand contagion processes in our modern world.

**Prerequisite(s):** NETS 5050 with a minimum grade of C ; NETS 5051 with a minimum grade of C

**NETS 5311. Physical and Digital Human Traces. (3 Hours)**
Examines how to use physical and digital human traces to understand how people interact with each other and their environment to gain fresh insights into human behavior. These traces can be captured from data sources such as mobile phones, social media posts, smart sensors, and transportation networks. The unprecedented availability of these data traces enables us to delve into theoretical and practical aspects of spatiotemporal data analysis techniques to characterize human behaviors. Studies technical proficiency required for investigating human dynamics to identify factors that determine how humans interact in physical spaces. Examines data science and statistical methods commonly employed in urban analytics to offer students an opportunity to obtain a robust comprehension of the methodologies, models, and data pertinent to study human dynamics.

**Prerequisite(s):** INSH 5301 with a minimum grade of C ; NETS 5050 with a minimum grade of C

**NETS 5314. Complexity in Social Systems. (3 Hours)**
Offers an in-depth exploration of complex systems and networks. Emphasizes the modeling of social phenomena using physical models. Focuses on quantitative phenomenology to understand and describe emergent features observed in large-scale social phenomena. Aims to identify general behavioral classes, not based on microscopic definitions but on universal, large-scale characteristics. This approach is used to uncover mechanisms behind various social dynamics such as opinion consensus, cultural dissemination, collective motion, and social hierarchies. Examines a range of contagion phenomena, from biological disease spread to social and technological contagions, highlighting the impact of complexity inherent in social, biological, and cultural aspects on these propagation processes.

**Prerequisite(s):** NETS 5050 with a minimum grade of C

**NETS 5360. Research Design for Social Networks. (4 Hours)**
Presents an in-depth exploration of experimental design in the context of social network analysis and a guide to the craft of research. Explores the knowledge and skills necessary to design and implement experiments that investigate social phenomena through the lens of network structures and dynamics. Every study is the result of a myriad of choices: What are the compelling questions and what data are needed to answer them? What exactly should you measure and how do you collect that data? What are the best ways to analyze these data? Considers digital trace, survey, qualitative data, and ethical considerations for each choice. Offers students an opportunity to develop a solid foundation in both social network analysis principles and experimental research methodologies.

**Prerequisite(s):** INSH 5301 with a minimum grade of C

**NETS 5411. Financial and Economic Networks. (3 Hours)**
Identifies the complex web of financial and economic interactions that shape our global economy. Examines a wide range of relevant and emerging topics of today's interconnected world and approaches to studying these networks. Investigates the integration of techniques, applications, and the impact of network theory in these fields. Explores in-depth three main topics: trade, financial, and socioeconomic networks. Delves into network models of trade, leveraging input-output data to understand production, as well as firm-level supply chain analysis. Considers topics of finance, including banking and online systems, as well as financial transactions. Draws insights into microeconomic topics of knowledge creation, the labor market, and income inequality.

**Prerequisite(s):** NETS 5050 with a minimum grade of C

**NETS 5515. Complex Network Analysis for Biological Systems. (4 Hours)**
Covers the properties of diverse biological networks and foundational computational methods for analyzing, visualizing, and performing statistical investigations of networked data. Investigates how physicists have uncovered remarkable regularities in networked systems by applying approaches from scaling theory to biological networks. Explores the diversity of biological networks and provides the foundational tools needed to study networks derived from real-world data, including tools from machine learning. Focusing on a series of case studies, studies how to elucidate the structure and function of biological networks using empirical data.

**Prerequisite(s):** NETS 5050 with a minimum grade of C ; NETS 5051 with a minimum grade of C

**NETS 5901. Visualizing Complex Networks. (2 Hours)**
Studies the knowledge and skills necessary to effectively visualize complex network data. Covers foundational principles of network data visualization and effective strategies to present core network properties to a range of different audiences. Offers students an opportunity to obtain experience using various network visualization tools such as Networkx and matplotlib, Gephi, and other web-based tools. Examines case studies to explore diverse network visualization approaches to effectively convey scientific insights, advance policy, and inform the public, including examples from such diverse fields as brain science, supply chains, epidemiology, and urban analytics. Students give and receive feedback, collectively building competency in how to create and interpret visualizations of complex data. Final projects are designed to prepare students for working with clients and collaborators from industry, nonprofits, government agencies, and research.

**Prerequisite(s):** NETS 5050 with a minimum grade of C ; NETS 5051 with a minimum grade of C

**NETS 5902. Communicating Network Data. (2 Hours)**
Examines critical aspects of conveying complex network data effectively and ethically. Explores not only how to simplify and articulate complex network concepts to various audiences but also grapples with the ethical implications of the work, ensuring that communication is not just effective but also responsible and legally compliant. This is done through a combination of lectures and reading, as well as through guest lecturers and case studies. Requires a final project presentation that is based on a previous project selected by the student and that offers new presentations of the material designed for two (imagined) audiences: a general audience and a technically trained audience. Designed to help students bridge the gap between technical network analysis and effective, ethical communication.

**Prerequisite(s):** NETS 5051 with a minimum grade of C

**NETS 6000. Professional Development for Co-op. (1 Hour)**
Introduces the cooperative education program. Offers students an opportunity to develop job-search and career-management skills; to assess their workplace skills, interests, and values and to discuss how they impact personal career choices; to prepare a professional resumé; and to learn proper interviewing techniques. Explores career paths, choices, professional behaviors, work culture, and career decision making.

**NETS 6061. Analyzing Higher-Order Networks. (2 Hours)**
Delves into specialized network structures including temporal networks, higher-order networks (such as simplicial complexes and hypergraphs), and multilayer networks. Explores the dynamic aspects of temporal networks, the rich representation of relationships in higher-order networks, and the interconnected systems modeled by multilayer networks. By mastering the analysis and modeling of these advanced network structures, aims to equip students to address complex real-world challenges across various domains, ranging from epidemiology and social sciences to transportation planning and resilience analysis.

**Prerequisite(s):** NETS 5050 with a minimum grade of C ; NETS 5051 with a minimum grade of C

**NETS 6063. Probabilistic Mathematics of Networks. (2 Hours)**
Introduces advanced probabilistic tools and statistical methodologies within the realm of network science. Offers students an opportunity to obtain the skills needed to navigate and analyze the complexities and inherent uncertainties of networked systems. Introduces basic probabilistic computing with probability generating functions, the development of message-passing algorithms, and their various applications in the field of network science. Focuses primarily on modeling complex dynamical systems and tackling statistical inference problems using real-world network data, demonstrating the depth and versatility of these techniques.

**Prerequisite(s):** INSH 5301 with a minimum grade of C ; NETS 5050 with a minimum grade of C

**NETS 6099. Special Topics in Complex Networks. (2 Hours)**
Delves into advanced and specialized topics within the interdisciplinary field of network science. Network science explores the structure, behavior, and dynamics of complex systems represented as networks, encompassing social, technological, biological, and physical systems. Examines in-depth cutting-edge research, theoretical frameworks, and practical applications to offer students an opportunity to obtain a deeper understanding of the current trends and challenges in network science.

**Prerequisite(s):** NETS 5050 with a minimum grade of C ; NETS 5052 with a minimum grade of C

**NETS 6107. Complex Network Analysis Research Rotation. (2 Hours)**
Offers students up to three lab rotations and self-directed exploration of how network science can model social, technical, physical, and epidemiological systems and solve applied societal problems.Diverse topics could include disease spreading, effects of public policies and health interventions, drug efficacy, improvement of health and security of human populations, science of success, shaping of social behavior, formulation of political beliefs, group decision making, geometry of networks, topological data analysis on graphs, anomaly detection, algorithmically infused societies, and unifying the physics of networks with the mining of graphs. After research rotations, students independently explore areas to apply their skill set and utilize research community to engage in outreach for workforce opportunities. May be repeated once.

**Prerequisite(s):** INSH 5301 with a minimum grade of C ; NETS 5001 with a minimum grade of C ; NETS 5002 with a minimum grade of C ; NETS 5103 with a minimum grade of C

**NETS 6108. Complex Network Analysis Capstone. (2 Hours)**
Offers students an opportunity to apply network analytic tools and network science concepts to a project that further develops skills and expands understanding of how to approach problems using network analytics and principles. Students may propose a topic or choose projects presented by a sponsoring organization or agency. Topics must be approved by the instructor, and students are expected to provide regular updates and present their final project. May be repeated once.

**Prerequisite(s):** INSH 5301 with a minimum grade of C ; NETS 5001 with a minimum grade of C ; NETS 5002 with a minimum grade of C ; NETS 5103 with a minimum grade of C

**NETS 6116. Network Science 2. (4 Hours)**
Continues an exploration of network science and the set of analytical, numerical, and modeling tools used to understand complex networks emerging in nature and technology. Focuses on the empirical study of real networks. Investigates the organizing principles that govern the emergence of networks and the set of tools necessary to characterize and model them. Offers students an opportunity to obtain a deeper understanding of complex systems.

**Prerequisite(s):** PHYS 5116 with a minimum grade of C or NETS 5116 with a minimum grade of C

**NETS 6962. Elective. (1-4 Hours)**
Offers elective credit for courses taken at other academic institutions. May be repeated without limit.

**NETS 6964. Co-op Work Experience. (0 Hours)**
Provides eligible students with an opportunity for work experience. May be repeated up to seven times.

**NETS 6990. Thesis. (2 Hours)**
Offers analytical, research, and/or experimental work conducted under the auspices of the department. May be repeated once.

**Prerequisite(s):** INSH 5301 with a minimum grade of B- ; NETS 5001 with a minimum grade of B- ; NETS 5002 with a minimum grade of B- ; NETS 5103 with a minimum grade of B-

**NETS 7332. Machine Learning with Graphs. (4 Hours)**
Covers a number of advanced topics in machine learning and data mining on graphs, including vertex classification, graph clustering, link prediction and analysis, graph distance functions, graph embedding and representation learning, deep learning for graphs, anomaly detection, graph summarization, network inference, adversarial learning on networks, and notions of fairness in social networks. Seeks to familiarize students with state-of-the-art descriptive and predictive algorithms on graphs. Requires a foundational understanding of calculus and linear algebra, probability, machine learning or data mining, algorithms, and programming skills.

**Prerequisite(s):** PHYS 5116 with a minimum grade of C

**NETS 7334. Social Networks. (4 Hours)**
Offers an overview of the literature on social networks, with literature from political science, sociology, economics, and physics. Analyzes the underlying topology of networks and how we visualize and analyze network data. Key topics include small-world literature and the spread of information and disease. Students who do not meet course prerequisites may seek permission of instructor.

**NETS 7335. Dynamical Processes in Complex Networks. (4 Hours)**
Immerses students in the modeling of dynamical processes (contagion, diffusion, routing, consensus formation, etc.) in complex networks. Includes guest lectures from local and national experts working in process modeling on networks. Dynamical processes in complex networks provide a rationale for understanding the emerging tipping points and nonlinear properties that often underpin the most interesting characteristics of sociotechnical systems. Reviews the recent progress in modeling dynamical processes that integrates the complex features and heterogeneities of real-world systems.

**Prerequisite(s):** NETS 5116 with a minimum grade of C- or PHYS 5116 with a minimum grade of C-

**NETS 7341. Network Economics. (4 Hours)**
Covers seminal works in the economics of information and networks, including Akerlof, Arrow, Spence, Stiglitz, and von Hayek. Proceeds through concepts of information, its value, and measurement; search and choice under uncertainty; signaling, screening, and how rational actors use information for private advantage; strategy-given network effects; two-sided (or multisided) network effects, organizational information processing, learning, and social networks; and other micro- and macroeconomic effects such as matching markets. Although primarily a theory course, it may be of interest to any student applying information economics and network economics in academic, commercial, or government policy contexts. Expects students to produce a major paper suitable for publication or inclusion in a thesis. Requires prior completion of graduate coursework in microeconomics and mathematics at the level of introductory calculus and statistics.

**NETS 7360. Research Design for Social Networks. (4 Hours)**
Analyzes the architecture of research—how to design ethical research projects that empower the researcher to make useful and interesting claims about the world. Topics include design research about social networks and how to measure such varied relational concepts such as friendship, love, and proximity; the effective study of "recycled" data—data not collected for research—such as Twitter, cell phone, or email data, and the ethical constraints in using this data; and how to design data collection so as to make robust causal claims.

**NETS 7976. Directed Study. (1-4 Hours)**
Offers independent work under the direction of a member of the program on a chosen topic. Course content depends on instructor. May be repeated without limit.

**NETS 7983. Topics. (4 Hours)**
Covers various topics in network science. May be repeated up to two times for up to 12 total credits.

**NETS 8941. Network Science Literature Review Seminar. (2 Hours)**
Critically evaluates recent articles in the academic literature surrounding topics and applied research in network science. May be repeated up to three times.

**NETS 8984. Research. (1-4 Hours)**
Offers advanced students an opportunity to work with an individual instructor on a topic related to current research. Instructor and student negotiate a written agreement as to what topic(s) are covered and what written or laboratory work forms the basis for the grade. Viewed as a lead-in to dissertation research. May be repeated without limit.

**NETS 8986. Research. (0 Hours)**
Offers an opportunity to conduct full-time research under faculty supervision. May be repeated without limit.

**NETS 9000. PhD Candidacy Achieved. (0 Hours)**
Indicates successful completion of the doctoral comprehensive exam.

**NETS 9990. Dissertation Term 1. (0 Hours)**
Offers experimental and theoretical work for PhD candidates. Requires written dissertation and final oral exam.

**Prerequisite(s):** NETS 9000 with a minimum grade of S

**NETS 9991. Dissertation Term 2. (0 Hours)**
Offers dissertation supervision by members of the department.

**Prerequisite(s):** NETS 9990 with a minimum grade of S

**NETS 9996. Dissertation Continuation. (0 Hours)**
Offers experimental and theoretical work for PhD candidates. Requires written dissertation and final oral exam.

**Prerequisite(s):** NETS 9991 with a minimum grade of S or Dissertation Check with a score of REQ