EN.553 (APPLIED MATHEMATICS & STATISTICS)

EN.553.100. Introduction to Applied Mathematics and Statistics. 1 Credit.
A seminar-style series of lectures and assignments to acquaint the student with a range of intellectual and professional activities performed by applied mathematicians and statisticians. Problems arising in applied mathematics and statistics are presented by department faculty and outside speakers. Recommended Course Background: one semester of Calculus.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.101. Freshman Experience in Applied Mathematics & Statistics. 1 Credit.
The aim of this course is to provide students with an opportunity to work on a project in a small group setting together with an AMS faculty member. Projects can be varied in nature depending on the faculty member working with a group. The goal of a group could be to develop knowledge of a domain area in which mathematics is applied, to develop knowledge of some technique(s) in applied mathematics, to bring applied mathematics to bear on some application, or to develop knowledge in some foundational topic in mathematics. Faculty will present possible topics to students in the first week of classes. Students will be asked to rank their interests (first choice, second choice, etc.), and will provide their schedules. Based on their preferences, their schedules, and subject to group size limitations, students will be organized into groups of size at most 3, and will be assigned to course sections in the second week of classes. One faculty member will lead each section and will arrange to meet with the group once per week for an hour.
Area: Quantitative and Mathematical Sciences

EN.553.105. Mathematics of Music. 3 Credits.
This course aims to promote students' understanding of some important mathematical concepts by focusing on music and the sounds made by musical instruments as an area of mathematical application. Students will be exposed to basic concepts in mathematics including Fourier series, linear algebra, fundamental ideas from signal processing, and stochastic process models. The structure, organization, and synthesis of sounds and combinations of sounds will be explored.
Area: Quantitative and Mathematical Sciences

EN.553.111. Statistical Analysis I. 4 Credits.
First semester of a general survey of statistical methodology. Topics include descriptive statistics, introductory probability, conditional probability, random variables, expectation, sampling, the central limit theorem, classical and robust estimation, confidence intervals, and hypothesis testing. Case studies from psychology, epidemiology, economics and other fields serve to illustrate the underlying theory. Some use of Minitab, Excel or R, but no prior computing experience is necessary. Recommended Course Background: four years of high school mathematics. Students who may wish to undertake more than two semesters of probability and statistics should consider EN.553.420-EN.553.430.
Prerequisite(s): Statistics Sequence restriction: students who have completed AS.230.205 may not enroll.;Statistics Sequence restriction: students who have completed any of these courses may not register: EN.553.211 OR EN.553.230 OR EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.430 OR EN.553.413 OR EN.560.435 OR AS.280.345 OR AS.200.314 OR AS.200.315 OR EN.560.348
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.112. Statistical Analysis II. 4 Credits.
Second semester of a general survey of statistical methodology. Topics include two-sample hypothesis tests, analysis of variance, linear regression, correlation, analysis of categorical data, and nonparametrics. Students who may wish to undertake more than two semesters of probability and statistics should strongly consider the EN.553.420-430 sequence.
Prerequisite(s): EN.553.111 OR AS.230.205 OR AS.280.345 OR credit for AP Statistics
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.171. Discrete Mathematics. 4 Credits.
Introduction to the mathematics of finite systems. Logic; Boolean algebra; induction and recursion; sets, functions, relations, equivalence, and partially ordered sets; elementary combinatorics; modular arithmetic and the Euclidean algorithm; group theory; permutations and symmetry groups; graph theory. Selected applications. The concept of a proof and development of the ability to recognize and construct proofs are part of the course. Recommended Course Background: Four years of high school mathematics.
Prerequisite(s): Students may not earn credit for EN.553.171 and EN.553.172.;EN.553.171 may not be taken after EN.553.471 or EN.553.472 or EN.553.671 or EN.553.672.
Corequisite(s): EN.553.171 may not be taken concurrently with EN.553.471 or EN.553.472 or EN.553.671 or EN.553.672.
Area: Quantitative and Mathematical Sciences

EN.553.172. Honors Discrete Mathematics. 4 Credits.
Introduction to the mathematics of finite systems. Logic; Boolean algebra; induction and recursion; sets, functions, relations, equivalence, and partially ordered sets; elementary combinatorics; modular arithmetic and the Euclidean algorithm; polynomials rings, group theory; permutations groups and Galois theory; graph theory. Selected applications. The concept of a proof and development of the ability to recognize and construct proofs and analyze algorithms are part of the course. Recommended Course Background: Four years of high school mathematics.
Prerequisite(s): Students may not earn credit for both EN.553.171 and EN.553.172.;EN.553.172 may not be taken after EN.553.471 OR EN.553.472 OR EN.553.671 OR EN.553.672
Area: Quantitative and Mathematical Sciences

EN.553.211. Probability and Statistics for the Life Sciences. 4 Credits.
This is an introduction to statistics aimed at students in the life sciences. The course will provide the necessary background in probability with treatment of independence, Bayes theorem, discrete and continuous random variables and their distributions. The statistical topics covered will include sampling and sampling distributions, confidence intervals and hypothesis testing for means, comparison of populations, analysis of variance, linear regression and correlation. Analysis of data will be done using Excel.
Prerequisite(s): AS.110.106 OR AS.110.108 OR AS.110.113;Statistics Sequence restriction: Students who have completed any of these courses may not register: EN.550.230 OR AS.280.345 OR AS.200.314 OR AS.200.315 OR EN.550.310 OR EN.550.311 OR EN.560.435 OR EN.550.420 OR EN.550.430 OR EN.560.348
Area: Quantitative and Mathematical Sciences

EN.553.230. Introduction to Biostatistics. 4 Credits.
A self-contained course covering various data analysis methods used in the life sciences. Topics include types of experimental data, numerical and graphical descriptive statistics, concepts of (and distinctions between) population and sample, basic probability, fitting curves to experimental data (regression analysis), comparing groups in populations (analysis of variance), methods of modeling probability (contingency tables and logistic regression). Prerequisite: 3 years of high school mathematics
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.281. Introduction to Mathematical Computing. 4 Credits.
This course introduces a variety of techniques for solving optimization problems in engineering and science on a computer using MATLAB. Topics include the programming language MATLAB, as well as optimization theory, algorithms, and applications. MATLAB optimization tools will also be explored. Algorithms to be covered will include gradient descent, Newton's method, and the simplex method. Applications will include constrained least squares regression, neural networks, and k-means clustering.
Prerequisite(s): (AS.110.107 OR AS.110.109 OR AS.110.113) AND (AS.110.201 OR AS.110.212 OR EN.553.291)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.291. Linear Algebra and Differential Equations. 4 Credits.
An introduction to the basic concepts of linear algebra, matrix theory, and differential equations that are used widely in modern engineering and science. Intended for engineering and science majors whose program does not permit taking both AS.110.201 and AS.110.302.
Prerequisite(s): AS.110.107 OR AS.110.109 OR AS.110.113
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.310. Probability & Statistics for the Physical Sciences & Engineering. 4 Credits.
An introduction to probability and statistics at the calculus level, intended for engineering and science students planning to take only one course on the topics. Combinatorial probability, independence, conditional probability, random variables, expectation and moments, limit theory, estimation, confidence intervals, hypothesis testing, tests of means and variances, goodness-of-fit. Recommended co-requisite: multivariable calculus.Students who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.
Prerequisite(s): (AS.110.108 AND AS.110.109) OR AS.110.113;Statistics Sequence restriction: Students who have completed any of these courses may not register:EN.553.311 OR EN.560.435 OR EN.553.420 OR EN.553.430 OR EN.560.348
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.311. Probability and Statistics for the Biological Sciences and Engineering. 4 Credits.
An introduction to probability and statistics at the calculus level, intended for students in the biological sciences planning to take only one course on the topics. This coursewill be at the same technical level as EN.553.310. Students are encouraged to consider EN.553.420-430 instead. Combinatorial probability, independence,conditional probability, random variables, expectation and moments, limit theory, estimation, confidence intervals, hypothesis testing, tests of means and variances, andgoodness-of-fit will be covered. Students who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.Recommended Course Corequisite: AS.110.202
Prerequisite(s): (AS.110.108 AND AS.110.109) OR AS.110.113;Statistics Sequence restriction: students who have completed any of these courses may not register: EN.553.310 OR EN.560.435 OR EN.553.420 OR EN.553.430 OR EN.560.348
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.361. Introduction to Optimization. 4 Credits.
An introductory survey of optimization methods, supporting mathematical theory and concepts, and application to problems of planning, design, prediction, estimation, and control in engineering, management, and science. Study of varied optimization techniques including linear programming, network-problem methods, dynamic programming, integer programming, and nonlinear programming. Students should be familiar with computing and linear algebra. Recommended Course Background: one year of calculusStudents who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.
Prerequisite(s): (AS.110.109 OR AS.110.113) AND (EN.553.291 OR AS.110.201 OR AS.110.212)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.362. Introduction to Optimization II. 4 Credits.
An introductory survey of optimization methods, supporting mathematical theory and concepts, and application to problems of planning, design, prediction, estimation, and control in engineering, management, and science. Study of varied optimization techniques including linear programming, network-problem methods, dynamic programming, integer programming, and nonlinear programming.
Prerequisite(s): EN.550.361 AND (AS.110.202 OR AS.110.211)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.371. Cryptology and Coding. 4 Credits.
Computing experience. A first course in the mathematical theory of secure and reliable electronic communication. Cryptology is the study of secure communication: How can we ensure the privacy of messages? Coding theory studies how to make communication reliable: How can messages be sent over noisy lines? Topics include finite field arithmetic, error-detecting and error-correcting codes, data compressions, ciphers, one-time pads, the Enigma machine, one-way functions, discrete logarithm, primality testing, secret key exchange, public key cryptosystems, digital signatures, and key escrow.
Prerequisite(s): EN.550.171 AND (EN.550.291 OR AS.110.201 OR AS.110.212)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.383. Scientific Computing with Python. 4 Credits.
In this course, we will study numerical methods, and scientific computing using the Python language. We will discuss topics in numerical analysis, such as equation solving, differential equations, interpolation, integration etc. We will also introduce image analysis techniques such as filtering, denoising, inpainting, and segmentation. We will discuss core computer language concepts, algorithms, and data-structures using Python. No previous experience with computer programming is needed.
Prerequisite(s): (EN.550.291 OR AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211)
Area: Quantitative and Mathematical Sciences

EN.553.385. Numerical Linear Algebra. 4 Credits.
A first course on computational linear algebra and applications. Topics include floating-point arithmetic, algorithms and convergence, Gaussian elimination for linear systems, matrix decompositions (LU, Cholesky, QR), iterative methods for systems (Jacobi, Gauss–Seidel), and approximation of eigenvalues (power method, QR-algorithm). Theoretical topics such as vector spaces, inner products, norms, linear operators, matrix norms, eigenvalues, and canonical forms of matrices (Jordan, Schur) are reviewed as needed. Matlab is used to solve all numerical exercises; no previous experience with computer programming is required.
Prerequisite(s): (EN.553.291 OR AS.110.201 OR AS.110.212) AND (AS.110.202 OR AS.110.211)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.386. Scientific Computing: Differential Equations. 4 Credits.
A first course on computational differential equations and applications. Topics include floating-point arithmetic, algorithms and convergence, root-finding (midpoint, Newton, and secant methods), numerical differentiation and integration, and numerical solution of initial value problems (Runge–Kutta, multistep, extrapolation methods, stability, implicit methods, and stiffness). Theoretical topics such as existence, uniqueness, and stability of solutions to initial-value problems, conversion of higher order/ non-autonomous equations to systems, etc., will be covered as needed. Matlab is used to solve all numerical exercises; no previous experience with computer programming is required.
Prerequisite(s): (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.302 OR AS.110.306).
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.388. Scientific Computing: Differential Equations in Vector Spaces. 4 Credits.
A first course on computational differential equations in vector spaces and applications, a continuation of EN.550.385. Topics include root-finding for nonlinear systems of equations (bisection, Newton, and secant methods), numerical differentiation and integration, and numerical solution of initial-value problems (Runge–Kutta, multistep, extrapolation methods, stability, implicit methods, and stiffness) and boundary-value problems (shooting method, relaxation) for ordinary differential equations in finite-dimensional vector spaces. Theoretical topics such as existence, uniqueness, and stability of solutions to initial-value problems, conversion of higher-order/non-autonomous equations to systems, etc., will be covered as needed. Matlab is used to solve all numerical exercises.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.391. Dynamical Systems. 4 Credits.
Mathematical concepts and methods for describing and analyzing linear and nonlinear systems that evolve over time. Topics include boundedness, stability of fixed points and attractors, feedback, optimality, Liapounov functions, bifurcation, chaos, and catastrophes. Examples drawn from population growth, economic behavior, physical and engineering systems. The main mathematical tools are linear algebra and basic differential equations.
Prerequisite(s): EN.553.291 OR AS.110.201 OR AS.110.211
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.400. Mathematical Modeling and Consulting. 4 Credits.
Creating, analyzing and evaluating optimization and mathematical models using case studies. Project-oriented practice and guidance in modeling techniques, with emphasis on communication of methods and results. Applications may include transportation networks, scheduling, industrial processes, and telecommunications. Computation will be emphasized throughout using MATLAB.
Prerequisite(s): EN.553.361 OR EN.553.362;Students may receive credit for EN.550.400/EN.553.400 or EN.553.600, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.401. Introduction to Research. 3 Credits.
Aspects of the research process, including reading journal articles, writing mathematics, LaTeX, literature search, problem identification, problem-solving, oral presentations, Beamer, conference attendance, publication of results, and research ethics. An initial research experience, individually and/or in groups, with students identifying and developing projects in the mathematical sciences. Recent research topics have involved percolation, graph domination, Markov chains, birthday problems, gambler's ruin, integer programming, and rendezvous search problems. Instructor's permission required: Interested students must submit an unofficial transcript, vita, and personal statement to the instructor. Open only to undergraduates.
Area: Quantitative and Mathematical Sciences

EN.553.402. Research and Design in Applied Mathematics: Data Mining. 4 Credits.
The course will be project oriented with focus on practical uses of machine learning and data mining. Throughout the semester, teams of 4 will work on topics decided by the students and the instructor.
Prerequisite(s): EN.553.436
Area: Quantitative and Mathematical Sciences

EN.553.413. Applied Statistics and Data Analysis. 4 Credits.
An introduction to basic concepts, techniques, and major computer software packages in applied statistics and data analysis. Topics include numerical descriptive statistics, observations and variables, sampling distributions, statistical inference, linear regression, multiple regression, design of experiments, nonparametric methods, and sample surveys. Real-life data sets are used in lectures and computer assignments. Intensive use of statistical packages such as S+ to analyze data.
Prerequisite(s): EN.553.112 OR EN.553.310 OR EN.553.311 OR EN.553.420;Students may receive credit for EN.550.413/EN.553.413 or EN.553.613, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.414. Applied Statistics and Data Analysis II. 3 Credits.
Part II of a sequence on data analysis and linear models. Topics include categorical and discrete data analysis, mixed models, semiparametric and nonparametric regression, and generalized additive models. Applications of these methods using the R environment for statistical computing will be emphasized.
Prerequisite(s): EN.550.413;Students may receive credit for EN.550.414/EN.553.414 or EN.553.614, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.416. Introduction to Statistical Learning, Data Analysis and Signal Processing. 4 Credits.
Introduction to high dimensional data sets: key problems in statistical and machine learning. Geometric aspects. Principal component analysis, linear dimension reduction, random projections. Concentration phenomena: examples and basic inequalities. Metric spaces and embeddings thereof. Kernel methods. Nonlinear dimension reduction, manifold models. Regression. Vector spaces of functions, linear operators, projections. Orthonormal bases; Fourier and wavelet bases, and their use in signal processing and time series analysis. Basic approximation theory. Linear models, least squares. Bias and variance tradeoffs, regularization. Sparsity and compressed sensing. Multiscale methods. Graphs and networks. Random walks on graphs, diffusions, page rank. Block models. Spectral clustering, classification, semi-supervised learning. Algorithmic and computational aspects of the above will be consistently in focus, as will be computational experiments on synthetic and real data. Linear algebra will be used throughout the course, as will multivariable calculus and basic probability (discrete random variables). Basic experience in programming in C or MATLAB or R or Octave. Recommended Course Background: More than basic programming experience in Matlab or R; some more advanced probability (e.g. continuous random variables), some signal processing (e.g. Fourier transform, discrete and continuous).Co-listed with AS.110.446
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.417. Mathematical Modeling: Statistical Learning. 3 Credits.
Students will work independently or in groups on two or more projects using and developing machine learning methods such as linear and generalized linear regression, shrinkage method, Bayesian decision theory, variable selection, clustering, dimension reduction, functional data analysis, kernel smoothing methods and so on. These concepts will be briefly discussed in class, but some basic knowledge about them is expected. Some usual coding methods such as R, python, Matlab and C ++ will also be discussed in class. Successful works could gradually turn into a part of an undergraduate or graduate thesis, or research papers. This course emphasizes on both mathematical reasons behind a model and computational skills to implement.
Prerequisite(s): EN.550.436
Area: Quantitative and Mathematical Sciences

EN.553.420. Introduction to Probability. 4 Credits.
Probability and its applications, at the calculus level. Emphasis on techniques of application and on rigorous mathematical demonstration. Probability, combinatorial probability, random variables, distribution functions, important probability distributions, independence, conditional probability, moments, covariance and correlation, limit theorems. Students initiating graduate work in probability or statistics should enroll in EN.553.620 or EN.553.720. Prerequisites: one year of calculus. Corequisites: multivariable calculus and linear algebra.Students who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.
Prerequisite(s): AS.110.109 OR AS.110.113;Students may receive credit for EN.550.420/EN.553.420 or EN.553.620, but not both.;AS.110.201 OR AS.110.202 OR AS.110.211 OR AS.110.212, can be taken concurrently.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.426. Introduction to Stochastic Processes. 4 Credits.
Mathematical theory of stochastic processes. Emphasis on deriving the dependence relations, statistical properties, and sample path behavior including random walks, Markov chains (both discrete and continuous time), Poisson processes, martingales, and Brownian motion. Applications that illuminate the theory. Students may receive credit for EN.553.426 or EN.553.626.
Prerequisite(s): (EN.550.420 OR EN.553.620) AND (EN.550.291 OR AS.110.201 OR AS.110.212);Students may receive credit for EN.550.426/EN.553.426 or EN.553.626, but not both.
Corequisite(s): Students may not enroll in EN.553.420 in the same semester.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.427. Stochastic Processes and Applications to Finance. 4 Credits.
A development of stochastic processes with substantial emphasis on the processes, concepts, and methods useful in mathematical finance. Relevant concepts from probability theory, particularly conditional probability and conditional expection, will be briefly reviewed. Important concepts in stochastic processes will be introduced in the simpler setting of discrete-time processes, including random walks, Markov chains, and discrete-time martingales, then used to motivate more advanced material. Most of the course will concentrate on continuous-time stochastic processes, particularly martingales, Brownian motion, diffusions, and basic tools of stochastic calculus. Examples will focus on applications in finance, economics, business, and actuarial science.Students may only earn credit for one of EN.553.427 or EN.553.627.
Prerequisite(s): EN.553.420 OR EN.553.620;Students may receive credit for only one of EN.550.427, EN.553.427, OR EN.553.627
Area: Quantitative and Mathematical Sciences

EN.553.428. Stochastic Processes and Applications to Finance II. 4 Credits.
A basic knowledge of stochastic calculus and Brownian motion is assumed. Topics include stochastic differential equations, the Feynman-Kac formula and connections to partial differential equations, changes of measure, fundamental theorems of asset pricing, martingale representations, first passage times and pricing of path-dependent options, and jump processes.
Prerequisite(s): EN.553.427 OR EN.553.627;Students may receive credit for EN.550.428/EN.553.428 or EN.553.628, but not both.
Area: Quantitative and Mathematical Sciences

EN.553.429. Introduction to Research in Discrete Probability. 3 Credits.
Aspects of the research process, including reading and writing mathematics, LaTeX, literature search, problem identification, problem-solving, oral presentations, Beamer, conference attendance, publication of results, and research ethics. An initial research experience, individually and/or in groups, with students identifying and developing projects in discrete mathematics and probability, such as percolation, random graphs, random walks, birthday problems, gambler's ruin, coupon collector problems, and self-avoiding walks. Instructor's permission required. Open only to undergraduates.
Prerequisite(s): EN.553.171 AND (EN.553.420 OR EN.553.620);Students may receive credit for EN.550.429/EN.553.429 or EN.553.629, but not both.
Area: Quantitative and Mathematical Sciences

EN.553.430. Introduction to Statistics. 4 Credits.
Introduction to mathematical statistics. Finite population sampling, approximation methods,classical parametric estimation, hypothesis testing, analysis of variance, and regression. Bayesian methods.
Prerequisite(s): (EN.553.420 OR EN.553.620) AND (AS.110.201 OR AS.110.212 OR EN.553.291);Students may receive credit for EN.550.430/EN.553.430 or EN.553.630, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.431. Honors Introduction to Statistics. 4 Credits.
Introduction to the theory and methodology of mathematical statistics: parametric estimation, including asymptotic properties of estimators and approximation methods; hypothesis testing; analysis of variance; regression; bootstrapping and nonparametrics. Intended for students with a particular interest in the theoretical foundations of statistical procedures.
Prerequisite(s): EN.553.420 AND (AS.110.201 OR AS.110.212 OR EN.553.291) AND (AS.110.202 OR AS.110.211);Students may receive credit for only one of EN.553.430, EN.553.431 or EN.553.630.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.432. Bayesian Statistics. 3 Credits.
The course will cover Bayesian methods for exploratory data analysis. The emphasis will be on applied data analysis in various disciplines. We will consider a variety of topics, including introduction to Bayesian inference, prior and posterior distribution, hierarchical models, spatial models, longitudinal models, models for categorical data and missing data, model checking and selection, computational methods by Markov Chain Monte Carlo using R or Matlab. We will also cover some nonparametric Bayesian models if time allows, such as Gaussian processes and Dirichlet processes.
Prerequisite(s): (EN.553.420 OR EN.553.620) AND (EN.553.430 OR EN.553.630);Students may take only one of EN.550.632, EN.553.432, EN.553.632 or EN.553.732.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.433. Monte Carlo Methods. 4 Credits.
The objective of the course is to survey essential simulation techniques for popular stochastic models. The stochastic models may include classical time-series models, Markov chains and diffusion models. The basic simulation techniques covered will be useful in sample-generation of random variables, vectors and stochastic processes, and as advanced techniques, importance sampling, particle filtering and Bayesian computation may be discussed.
Prerequisite(s): Students may receive credit for EN550.433/EN.553.433 or EN.553.633, but not both.;EN.553.430 OR EN.553.630
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.436. Introduction to Data Science. 4 Credits.
Today the term Data Science is widely used covering a broad range of topics from mathematics and algorithms to actual data analysis and machine learning techniques. This course provides a thorough survey of relevant methods balancing the theory and the application aspects. Accordingly, the material and the discussions alternate between the methodology along with its underlying assumptions and the implementations along with their applications. We will cover several supervised methods for regression and classification, as well as unsupervised methods for clustering and dimensional reduction. To name a few in chronological order, the topics will include generalized linear regression, principal component analysis, nearest neighbor and Bayesian classifiers, support vector machines, logistic regression, decision trees, random forests, K-means clustering, Gaussian mixtures and Laplacian eigenmaps. The course uses Python and Jupyter Notebook and includes visualization techniques throughout the semester. Time permitting, an introduction to the Structured Query Language (SQL) is provided toward the end of the semester.
Prerequisite(s): Students may receive credit for EN.550.436/EN.553.436 or EN.553.636, but not both.;(AS.110.202 OR AS.110.211) AND (AS.110.201 OR AS.110.212 OR EN.550.291)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.439. Time Series Analysis. 3 Credits.
Time series analysis from the frequency and time domain approaches. Descriptive techniques; regression analysis; trends, smoothing, prediction; linear systems; serial correlation; stationary processes; spectral analysis.
Prerequisite(s): (EN.553.310[C] OR EN.553.311 OR EN.553.420 OR EN.553.620) AND (AS.110.201 OR AS.110.212 OR EN.553.291);Students may receive credit for EN.550.439/EN.553.439 or EN.553.639, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.441. Equity Markets and Quantitative Trading. 3 Credits.
This course introduces equity markets from a mathematical point of view. The properties of equities and equity-linked instruments will be described. Several quantitative trading strategies will be studied. Order execution tactics and the effect of market structure will be analyzed. Students will select a specialized aspect of the equity markets to investigate and complete a related independent project.
Prerequisite(s): EN.553.442 OR EN.553.642 or instructor's permission.;Students may receive credit for EN.550.441/EN.553.441 or EN.553.641, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.442. Investment Science. 4 Credits.
This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision-making. Topics covered in the course include the basic theory of interest and its application to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory, and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, portfolio evaluation. The student is expected to be comfortable with the use of mathematics as a method of deduction and problem solving. Students may not receive credit for both EN.550.342 and EN.553.442Students who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.
Prerequisite(s): Students may receive credit for only one of EN.550.342, EN.550.442, EN.553.442 or EN.553.642;(AS.110.109 OR AS.110.113) AND (EN.553.291 OR AS.110.201 OR AS.110.212) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.620 OR EN.550.430 EN.553.630)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.443. Financial Computing in C++. 4 Credits.
The first part of course, will introduce the basic concepts of C++ including variables, functions, pointers and references, function and operator overloading and along with inheritance and polymorphism, templates and the C++ Standard Library. Basic ideas of object-oriented design will be introduced. The second part of the course will cover computational techniques for solving mathematical problems arising in finance. Numerical solution of parabolic partial differential equations for option valuation and their relation to tree methods together with a basic introduction of concepts such as convergence and stability as applied to finite difference schemes. Prerequisites EN.550.427 Stochastic Processes and Applications to Finance. No prior experience with C/C++ is required.
Area: Quantitative and Mathematical Sciences

EN.553.444. Introduction to Financial Derivatives. 4 Credits.
This course will develop the mathematical concepts and techniques for modeling cash instruments and their hybrids and derivatives.
Prerequisite(s): Students may receive credit for EN.550.444/EN.553.444 or EN.553.644, but not both.;AS.110.302 AND EN.553.420
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.445. Interest Rate and Credit Derivatives. 4 Credits.
Advances in corporate finance, investment practice and the capital markets have been driven by the development of a mathematically rigorous theory for financial instruments and the markets in which they trade. This course builds on the concepts, techniques, instruments and markets introduced in EN.553.444. In addition to new topics in credit enhancement and structured securities, the focus is expanded to include applications in portfolio theory and risk management, and covers some numerical and computational approaches.
Prerequisite(s): EN.553.444 OR EN.553.644;Students may receive credit for EN.550.445/EN.553.445 or EN.553.645, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.446. Risk Measurement/Management in Financial Markets. 4 Credits.
This course applies advanced mathematical techniques to the measurement, analysis, and management of risk. The focus is on financial risk. Sources of risk for financial instruments (e.g., market risk, interest rate risk, credit risk) are analyzed; models for these risk factors are studied and the limitation, shortcomings and compensatory techniques are addressed.
Prerequisite(s): Students may receive credit for EN.550.446/EN.553.446 or EN.553.646, but not both.;EN.553.444 OR EN.553.644
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.447. Quantitative Portfolio Theory and Performance Analysis. 4 Credits.
This course focuses on modern quantitative portfolio theory, models, and analysis. Topics include intertemporal approaches to modeling and optimizing asset selection and asset allocation; benchmarks (indexes), performance assessment (including, Sharpe, Treynor and Jenson ratios) and performance attribution; immunization theorems; alpha-beta separation in management, performance measurement and attribution; Replicating Benchmark Index (RBI) strategies using cash securities / derivatives; Liability-Driven Investment (LDI); and the taxonomy and techniques of strategies for traditional management: Passive, Quasi-Passive (Indexing) Semi-Active (Immunization & Dedicated) Active (Scenario, Relative Value, Total Return and Optimization). In addition, risk management and hedging techniques are also addressed.
Prerequisite(s): Students may receive credit for 550.447/553.447 OR EN.553.647, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.448. Financial Engineering and Structured Products. 4 Credits.
This course focuses on structured securities and the structuring of aggregates of financial instruments into engineered solutions of problems in capital finance. Topics include the fundamentals of creating asset-backed and structured securities—including mortgage-backed securities (MBS), stripped securities, collateralized mortgage obligations (CMOs), and other asset-backed collateralized debt obligations (CDOs)—structuring and allocating cash-flows as well as enhancing credit; equity hybrids and convertible instruments; asset swaps, credit derivatives and total return swaps; assessment of structure-risk interest rate-risk and credit-risk as well as strategies for hedging these exposures; managing portfolios of structured securities; and relative value analysis (including OAS and scenario analysis).
Prerequisite(s): EN.553.442 OR EN.553.642 OR EN.553.444 OR EN.553.644;Students may receive credit for EN.550.448/EN.553.448 or EN.553.648, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.449. Advanced Equity Derivatives. 4 Credits.
This course will cover the pricing, trading and risk management of equity derivatives, with emphasis on more exotic derivatives such as path-dependent and multi-asset derivatives. The course will emphasize practical issues: students will build their own pricing and risk management tools, and gain experience simulating the dynamic hedging of a complex derivatives portfolio. Students will practice structuring and selling equity derivative products. Pricing issues such a model selection, unobservable input parameters and calibration will be discussed, and students will learn techniques to manage the often highly nonlinear and discontinuous risks associated with these products. The course will have a significant computing component: both in the classroom and as homework projects, students will use Excel, write VBA macros and write and call C++ routines in the Microsoft Windows environment (which is the most common computing environment used by the financial industry).
Prerequisite(s): Students may receive credit for EN.550.449/EN.553.449 or EN.553.649, but not both.;EN.553.444 OR EN.553.644
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.450. Computational Molecular Medicine. 4 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional “omics” data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful).
Prerequisite(s): (EN.553.420 OR EN.553.620) AND (EN.553.430 OR EN.553.630) OR equivalent courses in probability and statistics.;Students may receive credit for EN.550.450/EN.553.450 or EN.553.650, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.453. Mathematical Game Theory. 4 Credits.
Mathematical analysis of cooperative and noncooperative games. Theory and solution methods for matrix game (two players, zero-sum payoffs, finite strategy sets), games with a continuum of strategies, N-player games, games in rule-defined form. The roles of information and memory. Selected applications to economic, recreational, and military situations. Prereq: Multivariable Calculus, probability, linear algebra.
Prerequisite(s): Students may receive credit for EN.550.453/EN.553.453 or EN.553.653, but not both.;(AS.110.202 OR AS.110.211) AND (EN.550.420 OR EN.553.620) AND (EN.550.291 OR AS.110.201 OR AS.110.212)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.461. Optimization in Finance. 4 Credits.
A survey of many of the more important optimization methods and tools that are found to be useful in financial applications.
Prerequisite(s): Students may receive credit for EN.550.461/EN.553.461 or EN.553.661, but not both.;EN.553.442 OR EN.553.642 OR EN.553.444 OR EN.553.644
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.463. Network Models in Operations Research. 4 Credits.
In-depth mathematical study of network flow models in operations research, with emphasis on combinatorial approaches for solving them. Introduction to techniques for constructing efficient algorithms, and to some related data structures, used in solving shortest-path, maximum-volume, flow, and minimum-cost flow problems. Emphasis on linear models and flows, with brief discussion of non-linear models and network design.
Prerequisite(s): Students may receive credit for EN.550.463/EN.553.463 or EN.553.663, but not both.;EN.553.361 OR EN.553.661 OR EN.553.761 OR EN.553.461
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.465. Introduction to Convexity. 4 Credits.
Convexity is a simple mathematical concept that has become central in a diverse range of applications in engineering, science and business applications. Our main focus from the applications perspective will be the use of convexity within optimization problems, where convexity plays a key role in identifying the ’easy’ problems from the ’hard’ ones. The course will have an equal emphasis on expositing the rich mathematical structure of the field itself (properties of convex sets, convex functions, Helly-Caratheorody-Radon type theorems, polarity/duality, subdifferential calculus, polyhedral theory), and demonstrating how these ideas can be leveraged to model and solve optimization problems (via a detailed study of linear programming and basics of nonlinear convex optimization). Recommend Course Background: Familiarity with basic real analysis, linear algebra.
Prerequisite(s): Students may receive credit for EN.550.465/EN.553.465 or EN.553.665, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.467. Deep Learning in Discrete Optimization. 3 Credits.
The goal of the course is to examine research-level topics in the application of deep-learning techniques to the solution of computational problems in discrete optimization. The first part of the course will cover background material, introducing students to deep learning (focusing on practical aspects) and covering major topics in computational discrete optimization: heuristic methods, dynamic programming, linear programming, cutting planes, column generation, and branch-and-bound. We will then make an in-depth study of research papers where deep learning has been proposed as a solution-technique in discrete optimization, aiming towards discussionsof open research questions. Prerequisites: General mathematical maturity is expected: students should feel comfortable reading on their own Part 1 (Applied Math and Machine Learning Basics) in the text Deep Learning by Goodfellow, Bengio, and Courville.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.471. Combinatorial Analysis. 4 Credits.
Counting techniques: generating functions, recurrence relations, Polya’s theorem. Combinatorial designs: Latin squares, finite geometries, balanced incomplete block designs. Emphasis on problem solving. Recommended Course Background: AS.553.291 or AS.110.201Students who have received credit for AS.110.106 and/or AS.110.107 taken prior to Fall 2020 should contact the course instructor to determine whether they can receive permission to register for this course.
Prerequisite(s): Students may receive credit for EN.550.471/EN.553.471 or EN.550.671/EN.553.671, but not both.;(AS.110.109 OR AS.110.113) AND (AS.110.201 OR AS.110.212 OR EN.553.291)
Corequisite(s): EN.553.171 may not be taken concurrently with EN.553.471, EN.553.472, EN.553.671, or EN.553.672.
Area: Quantitative and Mathematical Sciences

EN.553.472. Graph Theory. 4 Credits.
Study of systems of “vertices” with some pairs joined by “edges.” Theory of adjacency, connectivity, traversability, feedback, and other concepts underlying properties important in engineering and the sciences. Topics include paths, cycles, and trees; routing problems associated with Euler and Hamilton; design of graphs realizing specified incidence conditions and other constraints. Attention directed toward problem solving, algorithms, and applications. One or more topics taken up in greater depth.
Prerequisite(s): EN.550.291 OR AS.110.201 OR AS.110.212;Students may receive credit for EN.550.472/EN.553.472 or EN.553.672, but not both.
Corequisite(s): EN.550.171 may not be taken concurrently with EN.550.471 or EN.550.472
Area: Quantitative and Mathematical Sciences

EN.553.473. Introduction to Nonlinear Dynamics and Chaos. 3 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos.
Prerequisite(s): Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.;((AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306)) OR EN.553.291
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.481. Numerical Analysis. 4 Credits.
Brief review of topics in elementary numerical analysis such as floating-point arithmetic, Gaussian elimination for linear equations, inter-polation and approximation. Core topics to be covered: numerical linear algebra including eigenvalue and linear least-squares problems, iterative algorithms for nonlinear equations and least squares problems, and convergence theory of numerical methods. Other possible topics: sparse matrix computations, numerical solution of partial differential equations, finite element methods, and parallel algorithms.
Prerequisite(s): (AS.110.202 OR AS.110.211) AND (EN.553.291 OR AS.110.201 OR AS.110.212) AND (EN.553.291 OR AS.110.302 OR AS.110.417 OR EN.553.386 OR EN.553.388 OR EN.553.391);Students may take only one of EN.550.681, EN.553.481, EN.553.681 or EN.553.781.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.485. Introduction to Harmonic Analysis and Its Applications. 4 Credits.
The course is an introduction to methods in harmonic analysis, in particular Fourier series, Fourier integrals, and wavelets. These methods will be introduced rigorously, together with their motivations and applications to the analysis of basic partial differential equations and integral kernels, signal processing, inverse problems, and statistical/machine.Co-listed with EN.553.685 and AS.110.433
Prerequisite(s): (AS.110.201 OR AS.110.212 OR EN.550.291/EN.553.291) AND (AS.110.202 OR AS.110.211[) AND (AS.110.405 OR AS.110.415);Students may receive credit for only one of the following: AS.110.433, EN.553.485, or EN.553.685.

EN.553.488. Computing for Applied Mathematics. 3 Credits.
The aim of this course is to develop students’ programming skills for solving problems commonly encountered in applied mathematics contexts. Specific problems that arise in applications of mathematics and data science (e.g. from finance, data analysis, or the physical sciences) are used to motivate concepts, techniques, and paradigms related to computation and programming. The Python language as well as a large collection of packages will be introduced. Students should be comfortable using computers but no prior programming background is required.
Prerequisite(s): Students may receive credit for EN.550.488/EN.553.488 or EN.553.688, but not both.;EN.553.310 OR EN.553.311 OR (EN.553.420 AND EN.553.430)
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.492. Mathematical Biology. 3 Credits.
This course will examine the mathematical methods relevant to modeling biological phenomena, particularly dynamical systems and probability. Topics include ordinary differential equations and their simulation; stability and phase plane analysis; branching processes; Markov chains; and stochastically perturbed systems. Biological applications will be drawn from population growth, predator-prey dynamics, epidemiology, genetics, intracellular transport, and neuroscience.
Prerequisite(s): (EN.553.420 OR EN.553.620) AND (AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306 OR EN.553.291);Students may receive credit for EN.550.492/EN.553.492 or EN.553.692, but not both.
Area: Natural Sciences, Quantitative and Mathematical Sciences

EN.553.493. Mathematical Image Analysis. 3 Credits.
This course gives an overview of various mathematical methods related to several problems encountered in image processing and analysis, and presents numerical schemes to address them. It will focus on problems like image denoising and deblurring, contrast enhancement, segmentation and registration. The different mathematical concepts shall be introduced during the course; they include in particular functional spaces such as Sobolev and BV, Fourier and wavelet transforms, as well as some notions from convex optimization and numerical analysis. Most of such methods will be illustrated with algorithms and simulations on discrete images, using MATLAB. Prerequisites : linear algebra, multivariate calculus, basic programming in MATLAB. Recommended Course Background: Real analysis
Prerequisite(s): (AS.110.202 OR AS.110.211) AND (EN.550.291 OR AS.110.201 OR AS.110.212);Students may receive credit for EN.550.493/EN.553.493 or EN.553.693, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.494. Applied and Computational Linear Algebra. 3 Credits.
In this seminar we plan to discuss generalizations of theorems and algorithms from matrix theory to hypermatrices. More specifically the seminar will discuss hypermatrix/tensor algebras, rank, spectra and transforms. Using the python friendly free open-source mathematics software SageMath and the hypermatrix algebra package we will discuss applications of hypermatrices to combinatorics, machine learning and data analysis.Preliminary knowledge of the Python language is not required.
Prerequisite(s): Students may receive credit for EN.550.494/EN.553.494 or EN.553.694, but not both.;AS.110.201 OR AS.110.212 OR EN.550.291
Area: Quantitative and Mathematical Sciences

EN.553.500. Undergraduate Research. 1 - 3 Credits.
Reading, research, or project work for undergraduate students. Pre-arranged individually between students and faculty.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.501. Senior Thesis. 3 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.502. Undergraduate Independent Study. 1 - 3 Credits.
Reading, research, or project work for undergraduate students. Pre-arranged individually between students and faculty. Recent topics and activities: percolation models, data analysis, course development assistance, and dynamical systems.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.503. Preparation for Research. 1 Credit.
Primarily an independent study course. Readings, assignments, and discussion to prepare students for research in applied mathematics and statistics. Topics include the research process, problem-solving, mathematical writing, LaTeX, Beamer, reading mathematics, literature search, oral presentations, REU programs, and the publication process. Brief meetings to be arranged. Students are expected to spend 3 to 4 hours per week in addition to the meetings. Grading is Satisfactory/Unsatisfactory only.

EN.553.512. Group Undergraduate Research. 1 - 3 Credits.
Reading, research, or project work for undergraduate students. Pre-arranged meetings between students and faculty. This section has a weekly research group meeting that students are expected to attend.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.552. Undergraduate Internship. 1 Credit.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.590. Internship - Summer. 1 Credit.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.597. Research-Summer. 3 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.599. Independent Study. 3 Credits.
Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration > Online Forms.

EN.553.600. Mathematical Modeling and Consulting. 4 Credits.
Creating, analyzing and evaluating optimization and mathematical models using case studies. Project-oriented practice and guidance in modeling techniques, with emphasis on communication of methods and results. Applications may include transportation networks, scheduling, industrial processes, and telecommunications. Computation will be emphasized throughout using MATLAB. Recommend Course Background: EN.553.361 OR EN.553.362.
Prerequisite(s): Students may receive credit for EN.550.400/EN.553.400 or EN.553.600, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.601. Introduction to Research. 3 Credits.
Aspects of the research process, including reading journal articles, writing mathematics, LaTeX, literature search, problem identification, problem-solving, oral presentations, Beamer, conference attendance, publication of results, and research ethics. An initial research experience, individually and/or in groups, with students identifying and developing projects in the mathematical sciences. Recent research topics have involved percolation, graph domination, Markov chains, birthday problems, gambler's ruin, integer programming, and rendezvous search problems. Instructor's permission required: Interested students must submit an unofficial transcript, vita, and personal statement to the instructor. Prereq: (553.171 or 553.172) and (553.420 or 553.620). Open only to graduate students.
Area: Quantitative and Mathematical Sciences

EN.553.602. Research and Design in Applied Mathematics: Data Mining. 4 Credits.
The course will be project oriented with focus on practical uses of machine learning and data mining. Throughout the semester, teams of 4 will work on topics decided by the students and the instructor.
Prerequisite(s): EN.553.636
Area: Quantitative and Mathematical Sciences

EN.553.613. Applied Statistics and Data Analysis. 4 Credits.
An introduction to basic concepts, techniques, and major computer software packages in applied statistics and data analysis. Topics include numerical descriptive statistics, observations and variables, sampling distributions, statistical inference, linear regression, multiple regression, design of experiments, nonparametric methods, and sample surveys. Real-life data sets are used in lectures and computer assignments. Intensive use of statistical packages such as S+ to analyze data. Recommend Course Background: EN.553.112 OR EN.553.310 OR EN.553.311 OR EN.553.420.
Prerequisite(s): Students may receive credit for EN.550.413/EN.553.413 or EN.553.613, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.614. Applied Statistics and Data Analysis II. 3 Credits.
Part II of a sequence on data analysis and linear models. Topics include categorical and discrete data analysis, mixed models, semiparametric and nonparametric regression, and generalized additive models. Applications of these methods using the R environment for statistical computing will be emphasized.
Prerequisite(s): Students may receive credit for EN.550.414/EN.553.414 or EN.553.614, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.620. Introduction to Probability. 4 Credits.
Probability and its applications, at the calculus level. Emphasis on techniques of application and on rigorous mathematical demonstration. Probability, combinatorial probability, random variables, distribution functions, important probability distributions, independence, conditional probability, moments, covariance and correlation, limit theorems. Auditors are not permitted. P/F grading not permitted. Recommended course background: (AS.110.109 or AS.110.113) and previously or concurrently (AS.110.202 or AS.110.201 or AS.110.212).
Prerequisite(s): Students may receive credit for EN.550.420/EN.553.420 or EN.553.620, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.626. Introduction to Stochastic Processes. 4 Credits.
Mathematical theory of stochastic processes. Emphasis on deriving the dependence relations, statistical properties, and sample path behavior including random walks, Markov chains (both discrete and continuous time), Poisson processes, martingales, and Brownian motion. Applications that illuminate the theory. Students may receive credit for EN.553.426 or EN.553.626. Recommended course background: (EN.553.291 OR AS.110.201 OR AS.110.212).
Prerequisite(s): EN.553.620;Students may receive credit for EN.550.426/ EN.553.426 or EN.553.626, but not both.
Corequisite(s): Students may not enroll in EN.553.620 in the same semester.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.627. Stochastic Processes and Applications to Finance. 4 Credits.
A development of stochastic processes with substantial emphasis on the processes, concepts, and methods useful in mathematical finance. Relevant concepts from probability theory, particularly conditional probability and conditional expection, will be briefly reviewed. Important concepts in stochastic processes will be introduced in the simpler setting of discrete-time processes, including random walks, Markov chains, and discrete-time martingales, then used to motivate more advanced material. Most of the course will concentrate on continuous-time stochastic processes, particularly martingales, Brownian motion, diffusions, and basic tools of stochastic calculus. Examples will focus on applications in finance, economics, business, and actuarial science. Recommend Course Background: EN.553.620.
Prerequisite(s): Students may receive credit for only one of EN.550.427, EN.553.427, EN.553.627
Area: Quantitative and Mathematical Sciences

EN.553.628. Stochastic Processes and Applications to Finance II. 4 Credits.
A basic knowledge of stochastic calculus and Brownian motion is assumed. Topics include stochastic differential equations, the Feynman-Kac formula and connections to partial differential equations, changes of measure, fundamental theorems of asset pricing, martingale representations, first passage times and pricing of path-dependent options, and jump processes.
Prerequisite(s): Students may receive credit for EN.550.428/EN.553.428 or EN.553.628, but not both.
Area: Quantitative and Mathematical Sciences

EN.553.629. Introduction to Research in Discrete Probability. 3 Credits.
Aspects of the research process, including reading and writing mathematics, LaTeX, literature search, problem identification, problem-solving, oral presentations, Beamer, conference attendance, publication of results, and research ethics. An initial research experience, individually and/or in groups, with students identifying and developing projects in discrete mathematics and probability, such as percolation, random graphs, random walks, birthday problems, gambler's ruin, coupon collector problems, and self-avoiding walks. Instructor's permission required.
Prerequisite(s): Students may receive credit for EN.550.429/EN.553.429 or EN.553.629, but not both.

EN.553.630. Introduction to Statistics. 4 Credits.
Introduction to the basic principles of mathematical statistics and data analysis. Emphasis on techniques of application. Classical parametric estimation, hypothesis testing, and multiple decision problems; linear models, analysis of variance, and regression; nonparametric and robust procedures; decision-theoretic setting, Bayesian methods. Recommended Course Background: EN.553.620 AND (AS.110.201 OR AS.110.212 OR EN.553.291).
Prerequisite(s): Students may receive credit for EN.550.430/EN.553.430 or EN.553.630, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.632. Bayesian Statistics. 3 Credits.
The course will cover Bayesian methods for exploratory data analysis. The emphasis will be on applied data analysis in various disciplines. We will consider a variety of topics, including introduction to Bayesian inference, prior and posterior distribution, hierarchical models, spatial models, longitudinal models, models for categorical data and missing data, model checking and selection, computational methods by Markov Chain Monte Carlo using R or Matlab. We will also cover some nonparametric Bayesian models if time allows, such as Gaussian processes and Dirichlet processes. Recommended prerequisites: EN.553.620 and (EN.553.630 or EN.553.730)
Prerequisite(s): Students may take only one of EN.550.632, EN.553.432, EN.553.632 or EN.553.732.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.633. Monte Carlo Methods. 4 Credits.
The objective of the course is to survey essential simulation techniques for popular stochastic models. The stochastic models may include classical time-series models, Markov chains and diffusion models. The basic simulation techniques covered will be useful in sample-generation of random variables, vectors and stochastic processes, and as advanced techniques, importance sampling, particle filtering and Bayesian computation may be discussed. Recommended Course Background: EN.553.630.
Prerequisite(s): Students may receive credit for EN.550.433/EN.553.433 or EN.553.633, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.636. Introduction to Data Science. 4 Credits.
Today the term Data Science is widely used covering a broad range of topics from mathematics and algorithms to actual data analysis and machine learning techniques. This course provides a thorough survey of relevant methods balancing the theory and the application aspects. Accordingly, the material and the discussions alternate between the methodology along with its underlying assumptions and the implementations along with their applications. We will cover several supervised methods for regression and classification, as well as unsupervised methods for clustering and dimensional reduction. To name a few in chronological order, the topics will include generalized linear regression, principal component analysis, nearest neighbor and Bayesian classifiers, support vector machines, logistic regression, decision trees, random forests, K-means clustering, Gaussian mixtures and Laplacian eigenmaps. The course uses Python and Jupyter Notebook and includes visualization techniques throughout the semester. Time permitting, an introduction to the Structured Query Language (SQL) is provided toward the end of the semester.
Prerequisite(s): Students may receive credit for EN.550.436/EN.553.436 or EN.553.636, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.639. Time Series Analysis. 3 Credits.
Time series analysis from the frequency and time domain approaches. Descriptive techniques; regression analysis; trends, smoothing, prediction; linear systems; serial correlation; stationary processes; spectral analysis. Recommended course background: EN.553.620 and (AS.110.201 OR AS.110.212 OR EN.553.291)
Prerequisite(s): Students may receive credit for EN.550.439/EN.553.439 or EN.553.639, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.641. Equity Markets and Quantitative Trading. 3 Credits.
This course introduces equity markets from a mathematical point of view. The properties of equities and equity-linked instruments will be described. Several quantitative trading strategies will be studied. Order execution tactics and the effect of market structure will be analyzed. Students will select a specialized aspect of the equity markets to investigate and complete a related independent project.
Prerequisite(s): Students may receive credit for EN.550.441/EN.553.441 or EN.553.641, but not both.;EN.553.442 or EN.553.642, or instructor's permission
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.642. Investment Science. 4 Credits.
This course offers a rigorous treatment of the subject of investment as a scientific discipline. Mathematics is employed as the main tool to convey the principles of investment science and their use to make investment calculations for good decision-making. Topics covered in the course include the basic theory of interest and its application to fixed-income securities, cash flow analysis and capital budgeting, mean-variance portfolio theory, and the associated capital asset pricing model, utility function theory and risk analysis, derivative securities and basic option theory, portfolio evaluation. The student is expected to be comfortable with the use of mathematics as a method of deduction and problem solving. Recommended Course Background: (AS.110.109 OR AS.110.113) AND (EN.553.291 OR AS.110.201 OR AS.110.212) AND (EN.553.310 OR EN.553.311 OR EN.553.420 OR EN.553.430).
Prerequisite(s): Students may receive credit for EN.550.342 or EN.550.442/EN.553.442 or EN.553.642, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.644. Introduction to Financial Derivatives. 4 Credits.
This course will develop the mathematical concepts and techniques for modeling cash instruments and their hybrids and derivatives. Recommended Course Background: AS.110.302 AND EN.553.620.
Prerequisite(s): Students may receive credit for EN.550.444/ EN.553.444 or EN.553.644, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.645. Interest Rate and Credit Derivatives. 4 Credits.
Advances in corporate finance, investment practice and the capital markets have been driven by the development of a mathematically rigorous theory for financial instruments and the markets in which they trade. This course builds on the concepts, techniques, instruments and markets introduced in EN.553.644. In addition to new topics in credit enhancement and structured securities, the focus is expanded to include applications in portfolio theory and risk management, and covers some numerical and computational approaches. Recommended Course Background: EN.553.644
Prerequisite(s): Students may receive credit for EN.550.445/EN.553.445 or EN.553.645, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.646. Risk Measurement/Management in Financial Markets. 4 Credits.
This course applies advanced mathematical techniques to the measurement, analysis, and management of risk. The focus is on financial risk. Sources of risk for financial instruments (e.g., market risk, interest rate risk, credit risk) are analyzed; models for these risk factors are studied and the limitation, shortcomings and compensatory techniques are addressed. Recommended Course Background: EN.553.644.
Prerequisite(s): Students may receive credit for EN.550.446/EN.553.446 or EN.553.646, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.647. Quantitative Portfolio Theory and Performance Analysis. 4 Credits.
This course focuses on modern quantitative portfolio theory, models, and analysis. Topics include intertemporal approaches to modeling and optimizing asset selection and asset allocation; benchmarks (indexes), performance assessment (including, Sharpe, Treynor and Jenson ratios) and performance attribution; immunization theorems; alpha-beta separation in management, performance measurement and attribution; Replicating Benchmark Index (RBI) strategies using cash securities / derivatives; Liability-Driven Investment (LDI); and the taxonomy and techniques of strategies for traditional management: Passive, Quasi-Passive (Indexing) Semi-Active (Immunization & Dedicated) Active (Scenario, Relative Value, Total Return and Optimization). In addition, risk management and hedging techniques are also addressed.
Prerequisite(s): Students may receive credit for (EN.550.447 OR EN.553.447) OR EN.553.647, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.648. Financial Engineering and Structured Products. 4 Credits.
This course focuses on structured securities and the structuring of aggregates of financial instruments into engineered solutions of problems in capital finance. Topics include the fundamentals of creating asset-backed and structured securities—including mortgage-backed securities (MBS), stripped securities, collateralized mortgage obligations (CMOs), and other asset-backed collateralized debt obligations (CDOs)—structuring and allocating cash-flows as well as enhancing credit; equity hybrids and convertible instruments; asset swaps, credit derivatives and total return swaps; assessment of structure-risk interest rate-risk and credit-risk as well as strategies for hedging these exposures; managing portfolios of structured securities; and relative value analysis (including OAS and scenario analysis).
Prerequisite(s): Students may receive credit for EN.550.448/EN.553.448 or EN.553.648, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.649. Advanced Equity Derivatives. 4 Credits.
This course will cover the pricing, trading and risk management of equity derivatives, with emphasis on more exotic derivatives such as path-dependent and multi-asset derivatives. The course will emphasize practical issues: students will build their own pricing and risk management tools, and gain experience simulating the dynamic hedging of a complex derivatives portfolio. Students will practice structuring and selling equity derivative products. Pricing issues such a model selection, unobservable input parameters and calibration will be discussed, and students will learn techniques to manage the often highly nonlinear and discontinuous risks associated with these products. The course will have a significant computing component: both in the classroom and as homework projects, students will use Excel, write VBA macros and write and call C++ routines in the Microsoft Windows environment (which is the most common computing environment used by the financial industry). Recommended Course Background: EN.553.444.
Prerequisite(s): Students may receive credit for EN.550.449/EN.553.449 or EN.553.649, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.650. Computational Molecular Medicine. 4 Credits.
Computational systems biology has emerged as the dominant framework for analyzing high-dimensional “omics” data in order to uncover the relationships among molecules, networks and disease. In particular, many of the core methodologies are based on statistical modeling, including machine learning, stochastic processes and statistical inference. We will cover the key aspects of this methodology, including measuring associations, testing multiple hypotheses, and learning predictors, Markov chains and graphical models. In addition, by studying recent important articles in cancer systems biology, we will illustrate how this approach enhances our ability to annotate genomes, discover molecular disease networks, detect disease, predict clinical outcomes, and characterize disease progression. Whereas a good foundation in probability and statistics is necessary, no prior exposure to molecular biology is required (although helpful). Recommended Course Background: EN.553.620 AND EN.553.630.
Prerequisite(s): Students may receive credit for EN.550.450/EN.553.450 or EN.553.650, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.653. Mathematical Game Theory. 4 Credits.
Mathematical analysis of cooperative and noncooperative games. Theory and solution methods for matrix game (two players, zero-sum payoffs, finite strategy sets), games with a continuum of strategies, N-player games, games in rule-defined form. The roles of information and memory. Selected applications to economic, recreational, and military situations. Prereq: Multivariable Calculus, probability, linear algebra. Recommended Course Background: (AS.110.202 OR AS.110.211) AND EN.553.620 AND (EN.553.291 OR AS.110.201 OR AS.110.212)
Prerequisite(s): Students may receive credit for EN.550.453/EN.553.453 or EN.553.653, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.661. Optimization in Finance. 4 Credits.
A survey of many of the more important optimization methods and tools that are found to be useful in financial applications. Recommended Course Background: EN.553.642 OR EN.553.644.
Prerequisite(s): Students may receive credit for EN.550.461/EN.553.461 or EN.553.661, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.663. Network Models in Operations Research. 4 Credits.
In-depth mathematical study of network flow models in operations research, with emphasis on combinatorial approaches for solving them. Introduction to techniques for constructing efficient algorithms, and to some related data structures, used in solving shortest-path, maximum-volume, flow, and minimum-cost flow problems. Emphasis on linear models and flows, with brief discussion of non-linear models and network design. Recommended Course Background: EN.553.361 OR EN.553.761 OR EN.553.661.
Prerequisite(s): Students may receive credit for EN.550.463/EN.553.463 or EN.553.663, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.665. Introduction to Convexity. 4 Credits.
Convexity is a simple mathematical concept that has become central in a diverse range of applications in engineering, science and business applications. Our main focus from the applications perspective will be the use of convexity within optimization problems, where convexity plays a key role in identifying the ’easy’ problems from the ’hard’ ones. The course will have an equal emphasis on expositing the rich mathematical structure of the field itself (properties of convex sets, convex functions, Helly-Caratheorody-Radon type theorems, polarity/duality, subdifferential calculus, polyhedral theory), and demonstrating how these ideas can be leveraged to model and solve optimization problems (via a detailed study of linear programming and basics of nonlinear convex optimization). Recommend Course Background: Familiarity with basic real analysis, linear algebra.
Prerequisite(s): Students may receive credit for EN.550.465 /EN.553.465 or EN.553.665, but not both.

EN.553.667. Deep Learning in Discrete Optimization. 3 Credits.
The goal of the course is to examine research-level topics in the application of deep-learning techniques to the solution of computational problems in discrete optimization. The first part of the course will cover background material, introducing students to deep learning (focusing on practical aspects) and covering major topics in computational discrete optimization: heuristic methods, dynamic programming, linear programming, cutting planes, column generation, and branch-and-bound. We will then make an in-depth study of research papers where deep learning has been proposed as a solution-technique in discrete optimization, aiming towards discussions of open research questions. Prerequisites: General mathematical maturity is expected: students should feel comfortable reading on their own Part 1 (Applied Math and Machine Learning Basics) in the text Deep Learning by Goodfellow, Bengio, and Courville.

EN.553.671. Combinatorial Analysis. 4 Credits.
An introduction to combinatorial analysis at the graduate level. Meets concurrently with 553.471. Counting techniques: generating functions, recurrence relations, Polya's theorem. Combinatorial designs: Latin squares, finite geometries, balanced incomplete block designs. Emphasis on problem solving. Recommended Course Background: EN.553.291 or AS.110.201
Prerequisite(s): Students may receive credit for EN.550.471/EN.553.471 or EN.553.671, but not both.

EN.553.672. Graph Theory. 4 Credits.
Study of systems of "vertices" with some pairs joined by "edges." Theory of adjacency, connectivity, traversability, feedback, and other concepts underlying properties important in engineering and the sciences. Topics include paths, cycles, and trees; routing problems associated with Euler and Hamilton; design of graphs realizing specified incidence conditions and other constraints. Attention directed toward problem solving, algorithms, and applications. One or more topics taken up in greater depth. Recommended Course Background: (EN.553.291 OR AS.110.201 OR AS.110.212)
Prerequisite(s): Students may receive credit for EN.550.472/EN.553.472 or EN.553.672, but not both.

EN.553.673. Introduction to Nonlinear Dynamics and Chaos. 3 Credits.
An introduction to the phenomenology of nonlinear dynamic behavior with emphasis on models of actual physical, chemical, and biological systems, involving an interdisciplinary approach to ideas from mathematics, computing, and modeling. The common features of the development of chaotic behavior in both mathematical models and experimental studies are stressed, and the use of modern data-mining tools to analyze dynamic data will be explored. Some computing experience is desirable. Emphasis will be placed on the geometric/visual computer-aided description and understanding of dynamics and chaos. Recommended course background: [(AS.110.201 or AS.110.212) and (AS.110.302 or AS.110.306)] or EN.553.291.
Prerequisite(s): Students may receive credit for only one of EN.553.473 OR EN.553.673 OR EN.540.468 OR EN.540.668.;((AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306)) OR EN.553.291

EN.553.681. Numerical Analysis. 4 Credits.
Brief review of topics in elementary numerical analysis such as floating-point arithmetic, Gaussian elimination for linear equations, interpolation and approximation. Core topics to be covered: numerical linear algebra including eigenvalue and linear least-squares problems, iterative algorithms for nonlinear equations and least squares problems, and convergence theory of numerical methods. Other possible topics: sparse matrix computations, numerical solution of partial differential equations, finite element methods, and parallel algorithms.Recommended Course Background: Multivariable calculus, linear algebra, and differential equations.
Prerequisite(s): Students may take only one of EN.550.681, EN.553.481, EN.553.681 or EN.553.781.

EN.553.685. Introduction to Harmonic Analysis and Its Applications. 4 Credits.
The course is an introduction to methods in harmonic analysis, in particular Fourier series, Fourier integrals, and wavelets. These methods will be introduced rigorously, together with their motivations and applications to the analysis of basic partial differential equations and integral kernels, signal processing, inverse problems, and statistical/machine. Recommended Course Background: (AS.110.201 OR AS.110.212 OR EN.553.291) AND (AS.110.202 OR AS.110.211) AND (AS.110.405 OR AS.110.415)
Prerequisite(s): Students may receive credit for only one of the following: AS.110.433, EN.553.485, or EN.553.685.

EN.553.688. Computing for Applied Mathematics. 3 Credits.
The aim of this course is to develop students' programming skills for solving solve problems commonly encountered in applied mathematics contexts. Specific problems that arise in applications of mathematics and data science (e.g. from finance, data analysis, or the physical sciences) are used to motivate concepts, techniques, and paradigms related to computation and programming. The Python language as well as a large collection of packages will be introduced. Recommended Course Background: EN.553.310 OR EN.553.311 OR (EN.553.420 AND EN.553.430). Students should be comfortable using computers but no prior programming background is required.
Prerequisite(s): Students may receive credit for EN.553.488 or EN.553.688, but not both.

EN.553.692. Mathematical Biology. 3 Credits.
This course will examine the mathematical methods relevant to modeling biological phenomena, particularly dynamical systems and probability. Topics include ordinary differential equations and their simulation; stability and phase plane analysis; branching processes; Markov chains; and stochastically perturbed systems. Biological applications will be drawn from population growth, predator-prey dynamics, epidemiology, genetics, intracellular transport, and neuroscience. Recommended Course Background: EN.553.620 AND (AS.110.201 OR AS.110.212) AND (AS.110.302 OR AS.110.306 OR EN.553.291)
Prerequisite(s): Students may receive credit for EN.550.492/EN.553.492 or EN.553.692, but not both.
Area: Natural Sciences, Quantitative and Mathematical Sciences

EN.553.693. Mathematical Image Analysis. 3 Credits.
This course gives an overview of various mathematical methods related to several problems encountered in image processing and analysis, and presents numerical schemes to address them. It will focus on problems like image denoising and deblurring, contrast enhancement, segmentation and registration. The different mathematical concepts shall be introduced during the course; they include in particular functional spaces such as Sobolev and BV, Fourier and wavelet transforms, as well as some notions from convex optimization and numerical analysis. Most of such methods will be illustrated with algorithms and simulations on discrete images, using MATLAB. Prerequisites : linear algebra, multivariate calculus, basic programming in MATLAB. Recommended Course Background: (AS.110.202 OR AS.110.211) AND (EN.553.291 OR AS.110.201 OR AS.110.212)
Prerequisite(s): Students may receive credit for EN.550.493/EN.553.493 or EN.553.693, but not both.
Area: Engineering, Quantitative and Mathematical Sciences

EN.553.694. Applied and Computational Linear Algebra. 3 Credits.
In this seminar we plan to discuss generalizations of theorems and algorithms from matrix theory to hypermatrices. More specifically the seminar will discuss hypermatrix/tensor algebras, rank, spectra and transforms. Using the python friendly free open-source mathematics software SageMath and the hypermatrix algebra package we will discuss applications of hypermatrices to combinatorics, machine learning and data analysis. Preliminary knowledge of the Python language is not required. Recommended Course Background: AS.110.212 OR AS.110.201 OR EN.553.291.
Prerequisite(s): Students may receive credit for EN.553.494 or EN.553.694, but not both.

EN.553.700. Master's Research. 3 - 10 Credits.
Reading, research, or project work for Master's level students. Arranged individually between students and faculty.

EN.553.701. Real Analysis: Preparation for the Ph.D. Introductory Examination. 4 Credits.
This course is designed to prepare students for the Real Analysis part of the introductory exam of the Department of Applied Mathematics and Statistics. In this course we will cover fundamental topics in real analysis, such as, Set Theory, The Topology of Euclidean Space, Continuous Mappings, Uniform Convergence, Differentiable Mappings, Inverse & Implicit Function Theorems, Integration Theory, Fourier Series, and Basics of Differential Equations.

EN.553.720. Probability Theory I. 4 Credits.
The course objectives are to develop probabilistic reasoning and problem solving approaches, to provide a rigorous mathematical basis for probability theory, and to examine several important results in the theory of probability. Topics include axiomatic probability, independence, random variables and their distributions, expectation, integration, variance and moments, probability inequalities, and modes of convergence of random variables. The course will include introductory measure theory as needed. Students are expected to have previous study of both analysis and probability. This course is the first half of a yearlong sequence. The second semester's course, EN.553.721 Probability Theory II, will cover classical limit theorems, characteristic functions, and conditional expectation. Prerequisite: real analysis (AS.110.405/AS.110.415)
Prerequisite(s): Students may take EN.550.620 or EN.553.720, but not both.

EN.553.721. Probability Theory II. 4 Credits.
Probability at the level of measure theory, focusing on limit theory. Modes of convergence, Poisson convergence, three-series theorem, strong law of large numbers, continuity theorem, central limit theory, Berry-Esseen theorem, infinitely divisible and stable laws. Recommended Course Background: EN.553.720 AND (AS.110.405 OR AS.110.415)

EN.553.722. Introduction to Stochastic Calculus. 3 Credits.
A graduate-level class on stochastic calculus, providing a rigorous introduction on stochastic integrals and differential equations.
Prerequisite(s): (AS.110.405 OR EN.553.701) AND EN.553.720

EN.553.723. Markov Chains. 3 Credits.
Recent advances in computer science, physics, and statistics have been made possible by corresponding sharply quantitative developments in the mathematical theory of Markov chains. Possible topics: rates of convergence to stationarity, eigenvalue techniques, Markov chain Monte Carlo, perfect simulation, self-organizing data structures, approximate counting and other applications to computer science, reversible chains, interacting particle systems.This course will be graded pass/fail.

EN.553.727. Large Deviations Theory. 3 Credits.
This course presents an introduction to the theory of large deviations, which provides a quantitative framework for understanding exponentially rare events. Topics encompass the development of large deviation principles in both finite and infinite-dimensional settings, from empirical measures of i.i.d samples to random perturbations of dynamical systems. Applications include problems in information theory, hypothesis testing, and transitions between steady states in biological and physical models.

EN.553.730. Statistical Theory. 4 Credits.
The fundamentals of mathematical statistics will be covered. Topics include: distribution theory for statistics of normal samples, exponential statistical models, the sufficiency principle, least squares estimation, maximum likelihood estimation, uniform minimum variance unbiased estimation, hypothesis testing, the Neyman-Pearson lemma, likelihood ratio procedures, the general linear model, the Gauss-Markov theorem, simultaneous inference, decision theory, Bayes and minimax procedures, chi-square methods, goodness-of-fit tests, and nonparametric and robust methods.
Prerequisite(s): Students may take EN.550.630 or EN.553.730, but not both.

EN.553.731. Statistical Theory II. 3 Credits.
Advanced concepts and tools fundamental to research in mathematical statistics and statistical inference: asymptotic theory;optimality; various mathematical foundations.

EN.553.732. Bayesian Statistics. 3 Credits.
The course will cover Bayesian methods for exploratory data analysis. The emphasis will be on applied data analysis in various disciplines. We will consider a variety of topics, including introduction to Bayesian inference, prior and posterior distribution, hierarchical models, spatial models, longitudinal models, models for categorical data and missing data, model checking and selection, computational methods by Markov Chain Monte Carlo using R or Matlab. We will also cover some nonparametric Bayesian models if time allows, such as Gaussian processes and Dirichlet processes. Prerequisite: 553.730 (recommended) or 553.630
Prerequisite(s): Students may take EN.550.632 or EN.553.732, but not both.

EN.553.733. Advanced Topics in Bayesian Statistics. 3 Credits.
This course covers advanced topics in Bayesian statistical analysis beyond the introductory course. Therefore knowledge of basic Bayesian statistics is assumed (at the level of "A first course in Bayesian statistical methods", by Peter Hoff (Springer, 2009). The models and computational methods will be introduced with emphasis on applications to real data problems. This course will cover nonparametric Bayesian models including Gaussian process, Dirichlet process (DP), Polya trees, dependent DP, Indian buffet process, etc. Recommended Course Background: EN.553.432 or EN.553.632 or EN.553.732 or permission from the instructor

EN.553.734. Introduction to Nonparametric Estimation. 3 Credits.
This course will cover the fundamental topics in the theory of nonparametric estimation. Several different nonparametric estimators (e.g., kernel, local polynomial, projection, spline, and trigonometric) and their statistical properties will be considered. Minimax lower bounds for a variety of nonparametric estimation problems will be discussed. A number of topics related to estimator asymptotic efficiency and adaptation will be studied. An overview of shape constrained nonparametric estimation will be presented for a variety of shape constraints (e.g., monotonicity and convexity).

EN.553.735. Topics in Statistical Pattern Recognition. 3 Credits.
The Dissimilarity Representation for Pattern Recognition. This course will investigate aspects of statistical inference and statistical pattern recognition associated with observing only dissimilarites between entities rather than observing feature vectors associated with the individual entities themselves.

EN.553.736. System Identification and Likelihood Methods. 2 Credits.
The focus of this roundtable-format course will be stochastic modeling as relates to system identification and maximum likelihood. The principles and algorithms being covered in this course have tremendous importance in the world at large. For example, maximum likelihood is arguably the most popular method for parameter estimation in most real-world applications. System identification is the term used in many fields to refer to the process of mathematical model building from experimental data, with a special focus on dynamical systems. The system identification process refers to several important aspects of model building, including selection of the model form (linear or nonlinear, static or dynamic, etc.), experimental design, parameter estimation, and model validation. This course will cover topics such as the maximum likelihood formulation and theory for dynamical systems, the EM (expectation-maximization) algorithm and its variants, Fisher information, common model structures, online versus offline estimation, the role of feedback in identification (i.e., open-loop versus closed-loop estimation), standard and extended Kalman filtering, and uncertainty characterization (e.g., confidence regions). Recommended Course Background: Undergraduate-level matrix theory and ordinary differential equations; graduate-level course in probability and statistics (e.g., 553.430 or equivalent; in particular, students should have prior exposure to maximum likelihood and Bayes' rule). Prior experience in data analysis and algorithms will be helpful.

EN.553.737. Distribution-free statistics and Resampling Methods. 3 Credits.
Distribution-free and resampling methods address statistical estimation, testing and validation under minimal assumptions on the true distribution of observed data, avoiding, in particular, to rely on some specific parametric class (e.g., Gaussian). The course will study the following topics: order statistics, rank-based methods, tests of independence, symmetry, location differences, scale differences and goodness-of-fit, permutation tests and bootstrap with an introduction to the problem of multiple comparisons.Recommended Courses: EN.553.430 or EN.553.730 or equivalent.

EN.553.738. High-Dimensional Approximation, Probability, and Statistical Learning. 3 Credits.
The course covers fundamental mathematical ideas for certain approximation and statistical learning problems in high dimensions. We start with basic approximation theory in low-dimensions, in particular linear and nonlinear approximation by Fourier and wavelets in classical smoothness spaces, and discuss applications in imaging, inverse problems and PDE's. We then introduce notions of complexity of function spaces, which will be important in statistical learning. We then move to basic problems in statistical learning, such as regression and density estimation. The interplay between randomness and approximation theory is introduced, as well as fundamental tools such as concentration inequalities, basic random matrix theory, and various estimators are constructed in detail, in particular multi scale estimators. At all times we consider the geometric aspects and interpretations, and will discuss concentration of measure phenomena, embedding of metric spaces, optimal transportation distances, and their applications to problems in machine learning such as manifold learning and dictionary learning for signal processing.

EN.553.739. Statistical Pattern Recognition Theory & Methods. 3 Credits.
This biennial course covers topics in the theory, methods, and applications of machine learning from an explicitly statistical perspective. Recommended Course Background: (EN.550.420 OR EN.553.420 OR EN.553.620) AND (EN.550.430 OR EN.553.430 OR EN.553.630)

EN.553.740. Machine Learning I. 3 Credits.
This course is the first part of a two-semester sequence that focuses on theoretical and practical aspects of statistical learning. After introducing background material on inner-product spaces, reproducing kernels and on optimization, the course discusses fundamental concepts of machine learning (such as generalization error, Bayes estimators and the bias vs. variance dilemma) and studies a collection of learning algorithms for classification and regression. The topics that are discussed include linear and kernel regression, support vector machines, lasso, logistic regression, decision trees and neural networks. Students will need a solid background in multivariate calculus, linear algebra, probability and statistics to complete the course.Recommended Course background: 553.620 and 553.630 or higher, and prerequisites for these courses.

EN.553.741. Machine Learning II. 3 Credits.
This course is the second part of a two-semester sequence that focuses on theoretical and practical aspects of statistical learning. The course will have two distinct parts. The first one will discuss some fundamentals of statistical learning theory, including some concentration inequality, generalization bounds and VC dimension. The second one will introduce problems and algorithms for unsupervised data analysis, including dimension reduction, manifold learning and clustering. Recommended course background: 553.740.

EN.553.742. Statistical Inference on Graphs. 3 Credits.
This course provides an introduction to and overview of current research in random graph inference, with a particular focus on spectral methods and their applications to inference for independent-edge random graphs. Topics include concentration inequalities; analysis of matrix perturbations; spectral decompositions of graph adjacency and Laplacian matrices; consistent estimation of latent variables associated to vertices; clustering, community detection, and classification in networks; and multi-sample hypothesis testing for graphs. Emphasis will be on a framework for establishing classical properties---consistency, normality, and efficiency---for estimators of graph parameters. Students will read papers in the literature and are expected to participate actively in class. Recommended prerequisites EN.553.792 and EN.553.630.

EN.553.749. Advanced Financial Theory. 3 Credits.
The first part of the course will review in depth the main instruments in the various asset classes, as well as the founding results on investment decision, capital budgeting and project financing. The second part will analyze the theory of the firm: capital structure, dilution and share repurchase, dividend policy, Modigliani- Miller theorem and will lead to the contingent claim pricing of corporate debt and equity as in Merton (1974) and its extensions . The third part will extend the CAPM to the Arbitrage Pricing Theory of Ross (1976) and its theoretical and operational consequences. The fourth part will be dedicated to the stochastic modelling of the yield curve to price caps, floors and swaptions, and their use in the Asset Liability Management of a bank and insurance company. This course will not begin until mid-October.
Prerequisite(s): Students may take EN.550.649 or EN.553.749, but not both.

EN.553.753. Commodity Markets and Trade Finance. 4 Credits.
The first half of this course will be devoted to energy markets, both in terms of the market itself and how to model peculiar features of this business. First we will discuss fossil fuels, including physical and financial natural gas and LNG; crude and refined petroleum commodities; and possibly coal markets. Then the focus will turn to electricity markets, including market structures; energy, capacity and ancillary services markets; characteristics of demand; power plant commitment and dispatch; the "stack" or market supply curve; characteristics of different plants and fuels; regional differences in markets; and hedging techniques from trading vanilla products all the way to complex multi-commodity structures. We will discuss renewable energy sources, their characteristics, economics, and effects on the larger market, as well as emissions markets as a way of removing pollution externalities. The first half will conclude by elaborating on risk management techniques; credit; legislation and regulation; and derivative accounting as time permits. The second half of the course will turn to shipping, metals and agricultural markets. The metal physical markets will be described, the major Exchanges presented (LME, SHFE), as well as the warehousing issues in the case of base metals. The case of precious metals will be singled out, and gold in particular; and finally uranium and rare earths. Agricultural (grains and softs) markets will be presented, together with the crucial issues of biofuels, fertilizers, water, and arable land. In all cases, there will be a large focus on the trading activities – both to hedge and to gain exposure to commodities – in spot and derivative markets. Numerous examples of forward curves will be provided, as well as volatility skews. The valuation of swaps, spread options and Asian options will be (re)derived. Students should have rudimentary knowledge of financial markets. Recommended Course Background: EN.553.620 and AS.110.108

EN.553.761. Nonlinear Optimization I. 3 Credits.
This course considers algorithms for solving various nonlinear optimization problems and, in parallel, develops the supporting theory. The primary focus will be on unconstrained optimization problems. Topics for the course will include: necessary and sufficient optimality conditions; steepest descent method; Newton and quasi-Newton based line-search, trust-region, and adaptive cubic regularization methods; linear and nonlinear least-squares problems; linear and nonlinear conjugate gradient methods. Recommended Course Background: Multivariable Calculus, Linear Algebra, Real Analysis such as AS.110.405
Prerequisite(s): Students may take EN.550.661 or EN.553.761, but not both.

EN.553.762. Nonlinear Optimization II. 3 Credits.
This course considers algorithms for solving various nonlinear optimization problems and, in parallel, develops the supporting theory. The primary focus will be on constrained optimization problems. Topics for the course will include: necessary and sufficient optimality conditions for constrained optimization; projected-gradient and two-phase accelerated subspace methods for bound-constrained optimization; simplex and interior-point methods for linear programming; duality theory; and penalty, augmented Lagrangian, sequential quadratic programming, and interior-point methods for general nonlinear programming. In addition, we will consider the Alternating Direction Method of Multipliers (ADMM), which is applicable to a huge range of problems including sparse inverse covariance estimation, consensus, and compressed sensing. Recommended Course Background: Multivariable Calculus, Linear Algebra, Real Analysis such as AS.110.405.

EN.553.763. Stochastic Search & Optimization. 3 Credits.
An introduction to stochastic search and optimization, including discrete and continuous optimization problems. Topics will include the "no free lunch" theorems, beneficial effects of injected Monte Carlo randomness, algorithms for global and local optimization problems, random search, recursive least squares, stochastic approximation, simulated annealing, evolutionary and genetic algorithms, machine (reinforcement) learning, and statistical multiple comparisons. Students should have knowledge of basic matrix algebra. Recommended Course Background: Graduate course in probability and statistics

EN.553.764. Modeling, Simulation, and Monte Carlo. 3 Credits.
Concepts and statistical techniques critical to constructing and analyzing effective simulations; emphasis on generic principles rather than specific applications. Topics include model building (bias-variance tradeoff, model selection,, Fisher information), benefits and drawbacks of simulation modeling, random number generation, simulation-based optimization, discrete multiple comparisons using simulations, Markov chain Monte Carlo (MCMC), and input selection using optimal experimental design.

EN.553.765. Convex Optimization. 3 Credits.
This course presents algorithms for convex optimization along with the supporting theoretical convergence results. The chosen topics covered, which are driven by big data and machine learning applications, include convex sets and functions, gradient methods (steepest descent, line searches, rates-of-convergence for weakly and strongly convex functions, Frank-Wolfe method), accelerated methods (heavy ball, Nesterov), stochastic gradient, coordinate descent, proximal and projected gradient methods, duality theory and duality-based algorithms (augmented Lagrangian, ADMM), and Newton/quasi-newton methods. Recommended Course Background: (AS.110.201 or AS. 110.212 or EN.550.291) and AS 110.405.

EN.553.766. Combinatorial Optimization. 3 Credits.
The main goal of this course is to introduce students to combinatorial optimization techniques. The first part of the course will focus on combinatorial algorithms for classical problems. The next part of the course will show how polyehdral theory can be used to deal with combinatorial optimization problems in a unifying manner. Familiarity with linear programming and algorithms desirable but not strictly required. Recommended Course Background: Linear Algebra.

EN.553.769. Topics in Discrete Optimization. 3 Credits.
We will study solution techniques for problems in discrete optimization, emphazing computational aspects of the theory and algorithms. Recommended Prerequisites: good backgrounds in linear programming and graph theory.

EN.553.781. Numerical Analysis. 4 Credits.
Brief review of topics in elementary numerical analysis such as floating-point arithmetic, Gaussian elimination for linear equations, inter-polation and approximation. Core topics to be covered: numerical linear algebra including eigenvalue and linear least-squares problems, iterative algorithms for nonlinear equations and least squares problems, and convergence theory of numerical methods. Other possible topics: sparse matrix computations, numerical solution of partial differential equations, finite element methods, and parallel algorithms.
Prerequisite(s): Students may take EN.550.681or EN.553.781, but not both.

EN.553.782. Statistical Uncertainty Quantification. 3 Credits.
This course introduces uncertainty quantification (UQ) on mathematical models and data, with emphasis on the use of stochastic processes and probability theory. Topics include computer experiments, designs, conditional probability, Bayesian inference, Gaussian stochastic processes, continuity, reproducing kernel Hilbert space, covariance functions, computer model emulation, parameter estimation, approximation, dynamic linear models, Kalman filter, computation, sensitivity analysis, functional ANOVA, model selection and calibration. Examples of some continuous time processes will be introduced, such as Brownian motion, Brownian bridge, O-U process, with extensions to multi-dimensional input space. Uncertainty analysis of mathematical models will be the focus from both theoretical and computational perspectives. Applications will concentrate on understanding and predicting the behavior of complex systems in science and engineering. Prerequisite EN.553.620 or EN.553.720 Recommended course background: EN.553.630 or EN.553.730.
Prerequisite(s): Students may take EN.550.782 or EN.553.782, but not both.

EN.553.783. Reliability Analysis. 3 Credits.
Reliability is the likelihood that an item will successfully perform to its specified requirements for a stated period of time and understanding its concepts has many applications within various scientific and engineering disciplines. Designed mainly for beginning level graduate students, this course consists of three major components. First, we will revisit some probability principles which will serve as the foundation for this course. Next, we will explore common lifetime models, model selection, and model fitting methods. Finally, we will look at reliability from a systems perspective where the focus will be on system reliability. Students are expected to present their findings on the applications on reliability presented in published works and/or via course projects. Recommended course background: EN.553.620.

EN.553.784. Mathematical Foundations of Computational Anatomy. 3 Credits.
The course will provide fundamental concepts and methods that pertain the analysis of the variation of anatomical shapes extracted from medical images. It will review basic properties of the most important shape representations (landmark, curves, surfaces, images…), describe distances and discrepancy measures that allow for their comparison, and introduce nonlinear optimal control methods that underlie the Large Deformation Diffeomorphic Metric Mapping (LDDMM) family of registration algorithms. The course will then discuss shape averaging methods and template-centered representations for the analysis of shape datasets.Recommended Course Background: Optimization (EN.553.361 or higher) and (AS.110.202 OR AS.110.211 or higher) AND AS.110.302 or higher.

EN.553.785. Asymptotic Analysis. 3 Credits.
Asymptotic analysis is a branch of mathematics that emphasizes finding approximate solutions for either small or large parameters, which have many benefits in various scientific and engineering disciplines. This is because, due to the complexity and mathematical formulation of the problem, analytical solutions are either difficult to obtain or impractical. The goal of this course is to introduce students to some of the most frequently used methods consisting of the following main components. First, an introduction to asymptotic sequences and expansions will be provided as well as some common techniques to obtaining asymptotic expansions on integrals. Next, some common transforms and their inverses will be introduced as well as techniques on finding the asymptotic representation of their inverses. Finally, we will examine some techniques for finding asymptotic representations of solutions resulting from ordinary differential equations. Throughout this course students will also be introduced to some special functions as practical examples to demonstrate how these techniques can be applied to provide robust approximations. Recommended Course Background: Differential Equations and either of the following courses AS.110.405, 110.311, or 110.607.

EN.553.790. Neural Networks and Feedback Control Systems. 2 Credits.
This roundtable course is an introduction to two related areas?neural networks (NNs) and control systems based on the use of feedback. Artificial NNs are effective conceptual and computational vehicles for many important applications; feedback control is relevant to virtually all natural and human-made systems. NNs are applied in areas such as system modeling and control, function approximation, time-series filtering/prediction/smoothing, speech/image/signal processing, and pattern recognition. Topics to be covered for NNs include network architecture, learning algorithms, and applications. Specific NNs discussed include perceptrons, feedforward networks with backpropagation, and recurrent networks. This course also provides an introduction to feedback control systems, including the role of feedback in regulating systems and in achieving stability in systems. We consider stochastic (noise) effects in feedback systems. We also consider the interface of NNs and control by discussing how NNs are used in building modern control systems in problems where standard methods are infeasible. Recommended Course Background: Matrix theory, differential equations, and a graduate course in probability and statistics.

EN.553.791. Internship - Financial Mathematics. 2 Credits.
This course is open only to AMS department master's students.

EN.553.792. Matrix Analysis and Linear Algebra. 4 Credits.
A second course in linear algebra with emphasis on topics useful in analysis, economics, statistics, control theory, and numerical analysis. Review of linear algebra, decomposition and factorization theorems, positive definite matrices, norms and convergence, eigenvalue location theorems, variational methods, positive and nonnegative matrices, generalized inverses.
Prerequisite(s): Students may take EN.550.692 or EN.553.792, but not both.

EN.553.793. Turbulence Theory. 3 Credits.
An advanced introduction to turbulence theory for graduate students in the physical sciences, engineering and mathematics. Both intuitive understanding and exact analysis of the fluid equations will be stressed. Previous familiarity with fluid mechanics is not required, although it could be helpful.

EN.553.794. Turbulence Theory II. 3 Credits.
This course will continue the theoretical investigation of fluid turbulence, directly following on from EN.550.693. Topics to be considered are turbulent vortex dynamics, Lagrangian dynamics, and special topics such as wall-bounded turbulence, free shear flows, two-dimensional and quasigeostrophic turbulence, MHD turbulence, etc. Cross-listed with Physics

EN.553.797. Introduction to Control Theory and Optimal Control. 3 Credits.
A control system is a dynamical system on which one can act through a parameter that can be chosen freely at any point in time. In this class, we will be interested in two main problems. The first one is controllability, which studies conditions for the existence of controls allowing an initial point to be driven to any other point. The second one is optimal control, in which we will study methods to minimize a certain cost over all possible controls, possibly with endpoint constraints. Such problems have many applications in engineering: crossing a river with minimal fuel, planning trajectories of rocket engines etc. Recommended Course Background: Multivariate Calculus, Linear Algebra, Differential Equations. Some familiarity with Optimization is recommended, but not mandatory.

EN.553.799. Topics In Applied Math. 3 Credits.
Analysis of Algorithms. This course in the probabilistic analysis of algorithms (AofA) will be accessible to any student who has had at least one course in probability and will be most beneficial to those who have had at least one probability course at the measure-theoretic level.The course will review basic topics from the theory of probability that have proved useful in AofA. It will provide introductions to more advanced AofA-relevant topics chosen from such topics as: Markov chains, branching processes, urn models, Poissonization (and de-Poissonization), various metrics on distributions, fixed-point characterizations of distributions, convergence of sequences of stochastic processes, perfect simulation using Markov chains (and otherwise), and large deviation principles.The course will interweave probability theory and applications to AofA, focusing on the fundamentally important and exceptionally rich example of limiting distributions for various ways of measuring the cost of executing the QuickSort and QuickSelect algorithms.

EN.553.800. Dissertation Research. 3 - 20 Credits.

EN.553.801. Department Seminar. 1 Credit.
A variety of topics discussed by speakers from within and outside the university. Required of all resident department graduate students.

EN.553.802. Graduate Independent Study. 3 Credits.

EN.553.806. Capstone Experience in Data Science. 3 - 10 Credits.
Project work for Data Science Master's students. Arranged individually between students and faculty.
Area: Quantitative and Mathematical Sciences

EN.553.810. Probability & Statistics. 1 - 4 Credits.
Prerequisite(s): EN.553.721

EN.553.822. Stochastic Calculus Seminar. 2 Credits.
Seminar and readings in stochastic calculus.

EN.553.826. Information Theory Seminar. 3 Credits.
Graduate seminar covering topics in information theory and information geometry. Topics may include large deviation theory, I-divergence, Fisher information and ergodic theory. Emphasis will be placed on developing a rigorous geometric understanding of methods and models in probability and statistics.Curse cannot be counted toward AMS Master's degree requirements
Prerequisite(s): EN.550.447 OR EN.550.630 or Permission of instructor.

EN.553.831. Advanced Topics in Nonparametric Bayesian Statistics. 3 Credits.
Will discuss advanced topics in nonparametric Bayesian statistics

EN.553.832. Machine Learning Journal Course. 3 Credits.
Journal course on machine learning topics.Course is restricted to first and second year AMS PhD students, and others by permission of instructor.

EN.553.833. Bayesian Modeling in Biomedical Applications. 3 Credits.
This topic course will cover Bayesian modeling in biomedical applications, especially in Electronic Health Record area. The knowledge of basic Bayesian statistics (at the level of "A first course in Bayesian statistical methods", by Peter Hoff (Springer, 2009)) and Nonparametric Bayesian statistics (e.g. Gaussian process, Dirichlet process (DP), dependent DP, Indian buffet process, etc) is assumed. Students will be required to do intensive literature readings on both Bayesian modeling from statistical journals and biomedical topics from medical journals, present papers of common interests, and discuss potential research ideas for their final project.

EN.553.847. Financial Mathematics Masters Seminar. 1 Credit.
This course is only open to students enrolled in the MSE in Financial Mathematics program. Advanced topics chosen according to the interests of the instructor and graduate students. The course will focus on recent research articles in the financial mathematics literature.

EN.553.892. Matrix Analysis II Seminar. 2 Credits.
Continuation of EN.550.692.