MATHEMATICS (MATH)

MATH 100
Introduction to the Profession
Introduces the student to the scope of mathematics as a profession, develops a sense of mathematical curiosity and problem solving skills, identifies and reinforces the student's career choices, and provides a mechanism for regular academic advising. Provides integration with other first-year courses. Introduces applications of mathematics to areas such as engineering, physics, computer science, and finance. Emphasis is placed on the development of teamwork skills.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 119
Geometry for Architects
Basic Euclidean and analytic geometry in two and three dimensions; trigonometry. Equations of lines, circles and conic sections; resolution of triangles; polar coordinates. Equations of planes, lines, quadratic surfaces. Applications. This course does not count toward business, computer science, engineering, mathematics, or natural science degree programs.
Lecture: 3 **Lab:** 1 **Credits:** 3

MATH 122
Introduction to Calculus
Basic concepts of calculus of a single variable; limits, continuity, derivatives, and integrals. Applications. This course does not count toward any business, computer science, engineering, mathematics, or natural science degree programs.
Prerequisite(s): MATH 119
Lecture: 3 **Lab:** 1 **Credits:** 3

MATH 130
Thinking Mathematically
This course allows students to discover, explore, and apply modern mathematical ideas. Emphasis is placed on using sound reasoning skills, visualizing mathematical concepts, and communicating mathematical ideas effectively. Classroom discussion and group work on challenging problems are central to the course. Topics from probability, statistics, logic, number theory, graph theory, combinatorics, chaos theory, the concept of infinity, and geometry may be included. This course does not count toward any computer science, engineering, mathematics, or natural science degree programs.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 131
Mathematics for Sustainability
The course provides students with the mathematical background and quantitative reasoning skills necessary to engage as informed citizens in discussions of sustainability related to climate change, resources, pollution, recycling, economic change, and similar matters of public interest. Introduces mathematical modeling techniques with examples related to environmental and economic sustainability. Emphasis is placed on quantitative reasoning, visualization of mathematical concepts and effective communication, both verbally and textually, through writing projects that require quantitative evidence to support an argument, classroom activities, and group work. Topics range from probability, statistics, decision theory, graph theory, physics, modeling, and algebra.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 147
College Algebra
This course is an in-depth study of the properties of the set of real numbers; operations with exponents (integer and rational), radicals, and logarithms; simplifying polynomials and rational expressions; and solving equations, inequalities, and systems of equations.
Lecture: 4 **Lab:** 0 **Credits:** 4

MATH 148
Preparation for Calculus
Review of algebra and analytic geometry. Functions, limits, derivatives. Trigonometry, trigonometric functions and their derivatives. Inverse functions, inverse trigonometric functions and their derivatives. Exponential and logarithmic functions. This course does not count toward any mathematics requirements in business, computer science, engineering, mathematics, or natural science degree programs.
Prerequisite(s): MATH 147 with min. grade of C
Lecture: 4 **Lab:** 0 **Credits:** 4

MATH 151
Calculus I
Analytic geometry. Functions and their graphs. Limits and continuity. Derivatives of algebraic and trigonometric functions. Applications of the derivative. Introduction to integrals and their applications.
Prerequisite(s): IIT Mathematics Placement score of 151 or MATH 145 with min. grade of C or MATH 148 with min. grade of C
Lecture: 4 **Lab:** 1 **Credits:** 5
Satisfies: Communications (C)

MATH 152
Calculus II
Transcendental functions and their calculus. Integration techniques. Applications of the integral. Indeterminate forms and improper integrals. Polar coordinates. Numerical series and power series expansions.
Prerequisite(s): MATH 149 with min. grade of C or MATH 151 with min. grade of C
Lecture: 4 **Lab:** 1 **Credits:** 5
Satisfies: Communications (C)

MATH 180
Fundamentals of Discrete Mathematics
Basic counting techniques, discrete probability, graph theory, algorithm complexity, logic and proofs, and other fundamental discrete topics. Required for students in the Bachelor of Information Technology and Management degree. This course does not count toward any computer science, engineering, mathematics, or natural science degree program. Credit will only be granted for one of MATH 180, MATH 230, and CS 330.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 191
Business Calculus
This is an introduction to basic calculus with an emphasis on applications to business economics, management, information science, and related fields. Topics include relations and functions, limits, continuity, derivatives, techniques of differentiation, chain rule, applications of differentiation, antiderivatives, the definite integral, the fundamental theorem of calculus, and applications of integration.
Prerequisite(s): MATH 148
Lecture: 4 **Lab:** 0 **Credits:** 4

MATH 192
Finite Mathematics
Finite Mathematics contains a carefully selected set of topics in probability and linear algebra, topics that provide the foundation for understanding any future statistics course and many phenomena you may well encounter in your life. The probability portion in the first half of the course provides the basis of understanding chance. It culminates in a discussion of Bayes' formula which is useful for understanding medical testing, drug testing, and lie detector testing and for understanding public policy for the use of these tests. The second half covers basic linear algebra culminating in linear optimization techniques which are useful in applications from baking to business. The two topics are tied together at the end of the course through a brief introduction to Markov chains, a common elementary mathematical model in social science, business, and science.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 225
Introductory Statistics
An introduction to statistics; data collection, description, visualization and analysis; basic probability; statistical reasoning and inference including hypothesis tests and confidence intervals: t-tests, chi-squared tests, ANOVA, correlation and regression.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 230
Introduction to Discrete Math
Sets, statements, and elementary symbolic logic; relations and digraphs; functions and sequences; mathematical induction; basic counting techniques and recurrence. Credit will not be granted for both CS 330 and MATH 230.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 251
Multivariate and Vector Calculus
Analytic geometry in three-dimensional space. Partial derivatives. Multiple integrals. Vector analysis. Applications.
Prerequisite(s): MATH 152
Lecture: 4 **Lab:** 1 **Credits:** 4

MATH 252
Introduction to Differential Equations
Linear differential equations of order one. Linear differential equations of higher order. Series solutions of linear DE. Laplace transforms and their use in solving linear DE. Introduction to matrices. Systems of linear differential equations.
Prerequisite(s): MATH 152
Lecture: 4 **Lab:** 0 **Credits:** 4

MATH 332
Elementary Linear Algebra
Systems of linear equations; matrix algebra, inverses, determinants, eigenvalues, and eigenvectors, diagonalization; vector spaces, basis, dimension, rank and nullity; inner product spaces, orthonormal bases; quadratic forms.
Prerequisite(s): MATH 251*, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 333
Matrix Algebra and Complex Variables
Vectors and matrices; matrix operations, transpose, rank, inverse; determinants; solution of linear systems; eigenvalues and eigenvectors. The complex plane; analytic functions; contour integrals; Laurent series expansions; singularities and residues.
Prerequisite(s): MATH 251
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 350
Introduction to Computational Mathematics
Study and design of mathematical models for the numerical solution of scientific problems. This includes numerical methods for the solution on linear and nonlinear systems, basic data fitting problems, and ordinary differential equations. Robustness, accuracy, and speed of convergence of algorithms will be investigated including the basics of computer arithmetic and round-off errors. Same as MMAE 350.
Prerequisite(s): (CS 104 or CS 105 or CS 115) and MATH 251 and MATH 252*, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 374
Probability and Statistics for Electrical and Computer Engineers
This course focuses on the introductory treatment of probability theory including: axioms of probability, discrete and continuous random variables, random vectors, marginal, joint, conditional and cumulative probability distributions, moment generating functions, expectations, and correlations. Also covered are sums of random variables, central limit theorem, sample means, and parameter estimation. Furthermore, random processes and random signals are covered. Examples and applications are drawn from problems of importance to electrical and computer engineers. Credit only granted for one of MATH 374, MATH 474, and MATH 475.
Prerequisite(s): MATH 251
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 380
Introduction to Mathematical Modeling
This course provides an introduction to problem-driven (as opposed to method-driven) applications of mathematics with a focus on design and analysis of models using tools from all parts of mathematics.
Prerequisite(s): (CS 104 or CS 105 or CS 115) and MATH 251 and MATH 252* and MATH 332*, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 400
Real Analysis
Real numbers, continuous functions; differentiation and Riemann integration. Functions defined by series.
Prerequisite(s): MATH 251 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 402
Complex Analysis
Analytic functions, conformal mapping, contour integration, series expansions, singularities and residues, and applications. Intended as a first course in the subject for students in the physical sciences and engineering.
Prerequisite(s): MATH 251 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 405
Introduction to Iteration and Chaos
Functional iteration and orbits, periodic points and Sharkovsky's cycle theorem, chaos and dynamical systems of dimensions one and two. Julia sets and fractals, physical implications.
Prerequisite(s): (MATH 251 and MATH 252 and MATH 332) or (MATH 252 and MATH 333 and MATH 251) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 410
Number Theory
Divisibility, congruencies, distribution of prime numbers, functions of number theory, diophantine equations, applications to encryption methods.
Prerequisite(s): MATH 230 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 420
Geometry
The course is focused on selected topics related to fundamental ideas and methods of Euclidean geometry, non-Euclidean geometry, and differential geometry in two and three dimensions and their applications with emphasis on various problem-solving strategies, geometric proof, visualization, and interrelation of different areas of mathematics. Permission of the instructor is required.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 425
Statistical Methods
Concepts and methods of gathering, describing and analyzing data including basic statistical reasoning, basic probability, sampling, hypothesis testing, confidence intervals, correlation, regression, forecasting, and nonparametric statistics. No knowledge of calculus is assumed. This course is useful for students in education or the social sciences. This course does not count for graduation in any mathematics programs. Credit not given for both MATH 425 and MATH 476.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 426
Statistical Tools for Engineers
Descriptive statistics and graphs, probability distributions, random sampling, independence, significance tests, design of experiments, regression, time-series analysis, statistical process control, introduction to multivariate analysis. Same as CHE 426. Credit not given for both Math 426 and CHE 426.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 430
Applied Algebra
Introduction to groups, homomorphisms, group actions, rings, field theory. Applications, including constructions with ruler and compass, solvability by radicals, error correcting codes.
Prerequisite(s): MATH 230 or MATH 332* or Graduate standing, An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 431
Computational Algebraic Geometry
Systems of polynomial equations and ideals in polynomial rings; solution sets of systems of equations and algebraic varieties in affine n-space; effective manipulation of ideals and varieties, algorithms for basic algebraic computations; Groebner bases; applications. Credit may not be granted for both MATH 431 and MATH 530.
Prerequisite(s): MATH 332 and MATH 230
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 435
Linear Optimization
Introduction to both theoretical and algorithmic aspects of linear optimization: geometry of linear programs, simplex method, anticycling, duality theory and dual simplex method, sensitivity analysis, large scale optimization via Dantzig-Wolfe decomposition and Benders decomposition, interior point methods, network flow problems, integer programming. Credit may not be granted for both MATH 435 and MATH 535.
Prerequisite(s): MATH 332
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 446
Introduction to Time Series
This course introduces the basic time series analysis and forecasting methods. Topics include stationary processes, ARMA models, spectral analysis, model and forecasting using ARMA models, nonstationary and seasonal time series models, multivariate time series, state-space models, and forecasting techniques.
Prerequisite(s): MATH 475 with min. grade of C or ECE 511 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 453
Combinatorics
Permutations and combinations; pigeonhole principle; inclusion-exclusion principle; recurrence relations and generating functions; enumeration under group action.
Prerequisite(s): MATH 230 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 454
Graph Theory and Applications
Directed and undirected graphs; paths, cycles, trees, Eulerian cycles, matchings and coverings, connectivity, Menger's Theorem, network flow, coloring, planarity, with applications to the sciences (computer, life, physical, social) and engineering.
Prerequisite(s): (MATH 230 and MATH 251) or (MATH 252 and MATH 230)
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 461
Fourier Series and Boundary-Value Problems
Fourier series and integrals. The Laplace, heat, and wave equations: Solutions by separation of variables. D'Alembert's solution of the wave equation. Boundary-value problems.
Prerequisite(s): (MATH 251 and MATH 252) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 474
Probability and Statistics
Elementary probability theory including discrete and continuous distributions, sampling, estimation, confidence intervals, hypothesis testing, and linear regression. Credit not granted for both MATH 474 and MATH 475.
Prerequisite(s): MATH 251 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 475
Probability
Elementary probability theory; combinatorics; random variables; discrete and continuous distributions; joint distributions and moments; transformations and convolution; basic theorems; simulation. Credit not granted for both MATH 474 and MATH 475.
Prerequisite(s): MATH 251 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 476
Statistics
Estimation theory; hypothesis tests; confidence intervals; goodness-of-fit tests; correlation and linear regression; analysis of variance; nonparametric methods.
Prerequisite(s): MATH 475 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 477
Numerical Linear Algebra
Fundamentals of matrix theory; least squares problems; computer arithmetic; conditioning and stability; direct and iterative methods for linear systems; eigenvalue problems. Credit may not be granted for both MATH 477 and MATH 577.
Prerequisite(s): MATH 350 or MMAE 350
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 478
Numerical Methods for Differential Equations
Polynomial interpolation; numerical integration; numerical solution of initial value problems for ordinary differential equations by single and multi-step methods, Runge-Kutta, Predictor-Corrector; numerical solution of boundary value problems for ordinary differential equations by shooting method, finite differences and spectral methods. Credit may not be granted for both MATH 478 and MATH 578.
Prerequisite(s): MATH 350 or MMAE 350
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 481
Introduction to Stochastic Processes
This is an introductory, undergraduate course in stochastic processes. Its purpose is to introduce students to a range of stochastic processes which are used as modeling tools in diverse fields of applications, especially in risk management applications for finance and insurance. The course covers basic classes of stochastic processes: Markov chains and martingales in discrete time; Brownian motion; and Poisson process. It also presents some aspects of stochastic calculus.
Prerequisite(s): (MATH 332 and MATH 475) or (MATH 475 and MATH 333)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 483
Design and Analysis of Experiments
Basic concepts for experimental design; introductory regression analysis; experiments with a single factor; experiments with more than one factor; full factorial experiments at two levels; fractional factorial design at two levels; full and fractional factorial design at three levels and at mixed levels; response surface methodology; introduction to computer experiments and space-filling design.
Prerequisite(s): MATH 476 or MATH 474
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 484
Regression
This course introduces the basic statistical regression model and design of experiments concepts. Topics include simple linear regression, multiple linear regression, least square estimates of parameters; hypothesis testing and confidence intervals in linear regression, testing of models, data analysis and appropriateness of models, generalized linear models, design and analysis of single-factor experiments.
Prerequisite(s): MATH 474 with min. grade of C or (MATH 476 with min. grade of C and MATH 475 with min. grade of C)
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 485
Introduction to Mathematical Finance
This is an introductory course in mathematical finance. Technical difficulty of the subject is kept at a minimum while the major ideas and concepts underlying modern mathematical finance and financial engineering are explained and illustrated. The course covers the binomial model for stock prices and touches on continuous time models and the Black-Scholes formula.
Prerequisite(s): MATH 475
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 486
Mathematical Modeling I
The course provides a systematic approach to modeling applications from areas such as physics and chemistry, engineering, biology, and business (operations research). The mathematical models lead to discrete or continuous processes that may be deterministic or stochastic. Dimensional analysis and scaling are introduced to prepare a model for study. Analytic and computational tools from a broad range of applied mathematics will be used to obtain information about the models. The mathematical results will be compared to physical data to assess the usefulness of the models. Credit may not be granted for both MATH 486 and MATH 522.
Prerequisite(s): MATH 251 and MATH 332 and MATH 252
Lecture: 3 **Lab:** 0 **Credits:** 3
Satisfies: Communications (C)

MATH 487
Mathematical Modeling II
The formulation of mathematical models, solution of mathematical equations, interpretation of results. Selected topics from queuing theory and financial derivatives.
Prerequisite(s): MATH 252 or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 488
Ordinary Differential Equations and Dynamical Systems
Boundary-value problems and Sturm-Liouville theory; linear system theory via eigenvalues and eigenvectors; Floquet theory; nonlinear systems: critical points, linearization, stability concepts, index theory, phase portrait analysis, limit cycles, and stable and unstable manifolds; bifurcation; and chaotic dynamics.
Prerequisite(s): (MATH 252 and MATH 251) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 489
Partial Differential Equations
First-order equations, characteristics. Classification of second-order equations. Laplace's equation; potential theory. Green's function, maximum principles. The wave equation: characteristics, general solution. The heat equation: use of integral transforms.
Prerequisite(s): MATH 252
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 491
Reading and Research
Independent reading and research. **Instructor permission required.**
Credit: Variable
Satisfies: Communications (C)

MATH 493
Summer Research and Independent Study
Students will conduct research work with advisers.
Lecture: 0 **Lab:** 0 **Credits:** 0

MATH 497
Special Problems
Special problems.
Credit: Variable
Satisfies: Communications (C)

MATH 500
Applied Analysis I
Measure Theory and Lebesgue Integration; Metric Spaces and Contraction Mapping Theorem, Normed Spaces; Banach Spaces; Hilbert Spaces.
Prerequisite(s): MATH 400 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 501
Applied Analysis II
Bounded Linear Operators on a Hilbert Space; Spectrum of Bounded Linear Operators; Fourier Series; Linear Differential Operators and Green's Functions; Distributions and the Fourier Transform; Differential Calculus and Variational Methods.
Prerequisite(s): MATH 500 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 512
Partial Differential Equations
Basic model equations describing wave propagation, diffusion and potential functions; characteristics, Fourier transform, Green function, and eigenfunction expansions; elementary theory of partial differential equations; Sobolev spaces; linear elliptic equations; energy methods; semigroup methods; applications to partial differential equations from engineering and science.
Prerequisite(s): MATH 461 with min. grade of C or MATH 489 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 515
Ordinary Differential Equations and Dynamical Systems
Basic theory of systems of ordinary differential equations; equilibrium solutions, linearization and stability; phase portraits analysis; stable unstable and center manifolds; periodic orbits, homoclinic and heteroclinic orbits; bifurcations and chaos; nonautonomous dynamics; and numerical simulation of nonlinear dynamics.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 519
Complex Analysis
Analytic functions, contour integration, singularities, series, conformal mapping, analytic continuation, multivalued functions.
Prerequisite(s): MATH 402 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 522
Mathematical Modeling
The course provides a systematic approach to modeling applications from areas such as physics and chemistry, engineering, biology, and business (operations research). The mathematical models lead to discrete or continuous processes that may be deterministic or stochastic. Dimensional analysis and scaling are introduced to prepare a model for study. Analytic and computational tools from a broad range of applied mathematics will be used to obtain information about the models. The mathematical results will be compared to physical data to assess the usefulness of the models. Credit may not be granted for both MATH 486 and MATH 522.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 523
Case Studies and Project Design in Applied Mathematics
The goal of the course is for students to learn how to use applied mathematics methods and skills to analyze real-world problems and to communicate their results in a non-academic setting. Students will work in groups of 2 or 3 to study and analyze problems and then provide useful information to a potential client. The time distribution is flexible and includes discussions of problems, presentation of needed background material and the required reports, and presentations by the teams. Several small projects will be examined and reported on.
Prerequisite(s): MATH 522
Credit: Variable

MATH 525
Statistical Models and Methods
Concepts and methods of gathering, describing and analyzing data including statistical reasoning, basic probability, sampling, hypothesis testing, confidence intervals, correlation, regression, forecasting, and nonparametric statistics. No knowledge of calculus is assumed. This course is useful for graduate students in education or the social sciences. This course does not count for graduation in any mathematics program. Credit given only for one of the following: MATH 425, MATH 476, or MATH 525.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 527
Machine Learning in Finance: From Theory to Practice
The purpose of this course is to introduce students to the theory and application of supervised and reinforcement learning to big data problems in finance. This course emphasizes the various mathematical frameworks for applying machine learning in quantitative finance, such as quantitative risk modeling with kernel learning and optimal investment with reinforcement learning. Neural networks are used to implement many of these mathematical frameworks in finance using real market data.
Prerequisite(s): MATH 475
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 530
Applied and Computational Algebra
Basics of computation with systems of polynomial equations, ideals in polynomial rings; solving systems of equations by Groebner bases; introduction to elimination theory; algebraic varieties in affine n-space; Zariski topology; dimension, degree, their computation and theoretical consequences.
Prerequisite(s): MATH 532 with min. grade of C or MATH 332 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 532
Linear Algebra
Matrix algebra, vector spaces, norms, inner products and orthogonality, determinants, linear transformations, eigenvalues and eigenvectors, Cayley-Hamilton theorem, matrix factorizations (LU, QR, SVD).
Prerequisite(s): MATH 332 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 535
Optimization I
Introduction to both theoretical and algorithmic aspects of linear optimization: geometry of linear programs, simplex method, anticycling, duality theory and dual simplex method, sensitivity analysis, large scale optimization via Dantzig-Wolfe decomposition and Benders decomposition, interior point methods, network flow problems, integer programming. Credit may not be given for both MATH 435 and MATH 535.
Prerequisite(s): MATH 332 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 540
Probability
Random events and variables, probability distributions, sequences of random variables, limit theorems, conditional expectations, and martingales.
Prerequisite(s): MATH 475 with min. grade of C and (MATH 400 with min. grade of C or Graduate standing)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 542
Stochastic Processes
This is an introductory course in stochastic processes. Its purpose is to introduce students into a range of stochastic processes, which are used as modeling tools in diverse field of applications, especially in the business applications. The course introduces the most fundamental ideas in the area of modeling and analysis of real World phenomena in terms of stochastic processes. The course covers different classes of Markov processes: discrete and continuous-time Markov chains, Brownian motion, and diffusion processes. It also presents some aspects of stochastic calculus with emphasis on the application to financial modeling and financial engineering.
Prerequisite(s): (MATH 332 with min. grade of C or MATH 333 with min. grade of C or Graduate standing) and (MATH 475 with min. grade of C or Graduate standing)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 543
Stochastic Analysis
This course will introduce the student to modern finite dimensional stochastic analysis and its applications. The topics will include: a) an overview of modern theory of stochastic processes, with focus on semimartingales and their characteristics, b) stochastic calculus for semimartingales, including Ito formula and stochastic integration with respect to semimartingales, c) stochastic differential equations (SDE's) driven by semimartingales, with focus on stochastic SDE's driven by Levy processes, d) absolutely continuous changes of measures for semimartingales, e) some selected applications.
Prerequisite(s): MATH 540 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 544
Stochastic Dynamics
This course is about modeling, analysis, simulation and prediction of dynamical behavior of complex systems under random influences. The mathematical models for such systems are in the form of stochastic differential equations. It is especially appropriate for graduate students who would like to use stochastic methods in their research, or to learn these methods for long term career development. Topics include white noise and colored noise, stochastic differential equations, random dynamical systems, numerical simulation, and applications to scientific, engineering and other areas.
Prerequisite(s): MATH 474 or MATH 475 with min. grade of B
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 545
Stochastic Partial Differential Equations
This course introduces various methods for understanding solutions and dynamical behaviors of stochastic partial differential equations arising from mathematical modeling in science, engineering, and other areas. It is designed for graduate students who would like to use stochastic methods in their research or to learn such methods for long term career development. Topics include the following: Random variables; Brownian motion and stochastic calculus in Hilbert spaces; Stochastic heat equation; Stochastic wave equation; Analytical and approximation techniques; Stochastic numerical simulations via Matlab; and applications to science, engineering, and other areas.
Prerequisite(s): MATH 540 with min. grade of C or MATH 543 with min. grade of C or MATH 544 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 546
Introduction to Time Series
This course introduces the basic time series analysis and forecasting methods. Topics include stationary processes, ARMA models, spectral analysis, model and forecasting using ARMA models, nonstationary and seasonal time series models, multivariate time series, state-space models, and forecasting techniques.
Prerequisite(s): MATH 475 with min. grade of C or ECE 511 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 548
Mathematical Finance I
This is an introductory course in mathematical finance. Technical difficulty of the subject is kept at a minimum by considering a discrete time framework. Nevertheless, the major ideas and concepts underlying modern mathematical finance and financial engineering are explained and illustrated.
Prerequisite(s): MATH 474 with min. grade of C or MATH 475 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 550
Topology
Topological spaces, continuous mappings and homeomorphisms, metric spaces and metrizability, connectedness and compactness, homotopy theory.
Prerequisite(s): MATH 556 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 553
Discrete Applied Mathematics I
A graduate-level introduction to modern graph theory through existential and algorithmic problems, and the corresponding structural and extremal results from matchings, connectivity, planarity, coloring, Turán-type problems, and Ramsey theory. Proof techniques based on induction, extremal choices, and probabilistic methods will be emphasized with a view towards building an expertise in working in discrete applied mathematics.
Prerequisite(s): MATH 454 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 554
Modern Methods in Discrete Applied Mathematics
A graduate-level course that introduces students in applied mathematics, computer science, natural sciences, and engineering, to the application of modern tools and techniques from various fields of mathematics to existential and algorithmic problems arising in discrete applied math. Probabilistic methods, entropy, linear algebra methods, Combinatorial Nullstellensatz, and Markov chain Monte Carlo, are applied to fundamental problems like Ramsey-type problems, intersecting families of sets, extremal problems on graphs and hypergraphs, optimization on discrete structures, sampling and counting discrete objects, etc.
Prerequisite(s): MATH 454 with min. grade of C or MATH 553 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 555
Tensor Analysis
Development of the calculus of tensors with applications to differential geometry and the formulation of the fundamental equations in various fields.
Prerequisite(s): (MATH 332 with min. grade of C and MATH 400 with min. grade of C) or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 556
Metric Spaces
Point-set theory, compactness, completeness, connectedness, total boundedness, density, category, uniform continuity and convergence, Stone-Weierstrass theorem, fixed point theorems.
Prerequisite(s): MATH 400 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 557
Probabilistic Methods in Combinatorics
Graduate level introduction to probabilistic methods, including linearity of expectation, the deletion method, the second moment method and the Lovasz Local Lemma. Many examples from classical results and recent research in combinatorics will be included throughout, including from Ramsey Theory, random graphs, coding theory and number theory.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 561
Algebraic and Geometric Methods in Statistics
Algebraic structures are present in a broad variety of statistical contexts, involving both parametric and non-parametric statistical models for continuous and discrete random variables. A broad range of algebraic tools is used to better understand model structure, improve statistical inference, and explore new classes of models. The course offers an overview of fundamental theoretical constructions relevant to some of the more popular recent applications in the field: exact conditional test for discrete data, likelihood geometry, parameter identifiability and model selection, network models with applications to social sciences and neuroscience, and phylogenetics and tree-based evolutionary models in biology.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 563
Mathematical Statistics
Theory of sampling distributions; principles of data reduction; interval and point estimation, sufficient statistics, order statistics, hypothesis testing, correlation and linear regression; introduction to linear models.
Prerequisite(s): MATH 474 with min. grade of C or MATH 475 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 564
Applied Statistics
This course introduces the basic statistical regression model and design of experiments concepts. Topics include simple linear regression, multiple linear regression, least square estimates of parameters; hypothesis testing and confidence intervals in linear regression, testing of models, data analysis and appropriateness of models, generalized linear models, design and analysis of single-factor experiments.
Prerequisite(s): MATH 474 with min. grade of C or MATH 476 with min. grade of C or MATH 563 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 565
Monte Carlo Methods in Finance
In addition to the theoretical constructs in financial mathematics, there are also a range of computational/simulation techniques that allow for the numerical evaluation of a wide range of financial securities. This course will introduce the student to some such simulation techniques, known as Monte Carlo methods, with focus on applications in financial risk management. Monte Carlo and Quasi Monte Carlo techniques are computational sampling methods which track the behavior of the underlying securities in an option or portfolio and determine the derivative's value by taking the expected value of the discounted payoffs at maturity. Recent developments with parallel programming techniques and computer clusters have made these methods widespread in the finance industry.
Prerequisite(s): MATH 474 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 566
Multivariate Analysis
Random vectors, sample geometry and random sampling, generalized variance, multivariate normal and Wishart distributions, estimation of mean vector, confidence region, Hotelling's T-square, covariance, principal components, factor analysis, discrimination, clustering.
Prerequisite(s): MATH 532 with min. grade of C and MATH 564 with min. grade of C and MATH 563 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 567
Advanced Design of Experiments
Basic concepts for experimental design; introductory regression analysis; experiments with a single factor; experiments with more than one factor; full factorial experiments at two levels; fractional factorial design at two levels; full and fractional factorial design at three levels and at mixed levels; response surface methodology; introduction to computer experiments and space-filling design.
Prerequisite(s): MATH 474 with min. grade of C or MATH 476 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 568
Topics in Statistics
Categorical data analysis, contingency tables, log-linear models, nonparametric methods, sampling techniques.
Prerequisite(s): MATH 563 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 569
Statistical Learning
The wealth of observational and experimental data available provides great opportunities for us to learn more about our world. This course teaches modern statistical methods for learning from data, such as regression, classification, kernel methods, and support vector machines.
Prerequisite(s): (MATH 474 with min. grade of C or MATH 475 with min. grade of C or Graduate standing) and (MATH 350 with min. grade of C or Graduate standing)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 571
Data Preparation and Analysis
This course surveys industrial and scientific applications of data analytics with case studies including exploration of ethical issues. Students will learn how to prepare data for analysis, perform exploratory data analysis, and develop meaningful data visualizations. They will work with a variety of real world data sets and learn how to prepare data sets for analysis by cleaning and reformatting. Students will also learn to apply a variety of different data exploration techniques including summary statistics and visualization methods.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 572
Data Science Practicum
In this project-oriented course, students will work in small groups to solve real-world data analysis problems and communicate their results. Innovation and clarity of presentation will be key elements of evaluation. Students will have an option to do this as an independent data analytics internship with an industry partner.
Prerequisite(s): SCI 522 with min. grade of C and (CSP 571 with min. grade of C or MATH 571 with min. grade of C)
Lecture: 3 **Lab:** 3 **Credits:** 6

MATH 573
Reliable Mathematical Software
Many mathematical problems cannot be solved analytically or by hand in a reasonable amount of time; so, turn to mathematical software to solve these problems. Popular examples of general-purpose mathematical software include Mathematica, MATLAB, the NAG Library, and R. Researchers often find themselves writing mathematical software to demonstrate their new ideas or using mathematical software written by others to solve their applications. This course covers the ingredients that go into producing mathematical software that is efficient, robust, and trustworthy. Students will write their own packages or parts of packages to practice the principles of reliable mathematical software.
Lecture: 1 **Lab:** 0 **Credits:** 0

MATH 574
Bayesian Computational Statistics
Rigorous introduction to the theory of Bayesian statistical inference and data analysis including prior and posterior distributions, Bayesian estimation and testing, Bayesian computation theories and methods, and implementation of Bayesian computation methods using popular statistical software.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 575
Statistical Analysis of Financial Data
The objective of this course is to introduce students to modern data analysis used in the financial industry, and to provide students with the necessary statistical toolkit to analyze and extract information from financial data. An important part of the course is the implementation of those statistical methods via Python/R, using real market data.
Prerequisite(s): MATH 474
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 577
Computational Mathematics I
Fundamentals of matrix theory; least squares problems; computer arithmetic, conditioning and stability; direct and iterative methods for linear systems; eigenvalue problems. Credit may not be granted for both Math 577 and Math 477. Prerequisite: An undergraduate numerical course, such as MATH 350 or instructor permission.
Prerequisite(s): MATH 350 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 578
Computational Mathematics II
Polynomial interpolation; numerical solution of initial value problems for ordinary differential equations by single and multi-step methods, Runge-Kutta, Predictor-Corrector; numerical solution of boundary value problems for ordinary differential equations by shooting method, finite differences and spectral methods. Credit may not be granted for both MATH 578 and MATH 478. Prerequisite: An undergraduate numerical course, such as MATH350 or instructor's consent.
Prerequisite(s): MATH 350 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 579
Complexity of Numerical Problems
This course is concerned with a branch of complexity theory. It studies the intrinsic complexity of numerical problems, that is, the minimum effort required for the approximate solution of a given problem up to a given error. Based on a precise theoretical foundation, lower bounds are established, i.e. bounds that hold for all algorithms. We also study the optimality of known algorithms, and describe ways to develop new algorithms if the known ones are not optimal.
Prerequisite(s): MATH 350 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 581
Finite Element Method
Various elements, error estimates, discontinuous Galerkin methods, methods for solving system of linear equations including multigrid. Applications.
Prerequisite(s): MATH 350 with min. grade of C or MATH 489 with min. grade of C or Graduate standing
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 582
Mathematical Finance II
This course is a continuation of Math 485/548. It introduces the student to modern continuous time mathematical finance. The major objective of the course is to present main mathematical methodologies and models underlying the area of financial engineering, and, in particular, those that provide a formal analytical basis for valuation and hedging of financial securities.
Prerequisite(s): (MATH 485 with min. grade of C or MATH 548 with min. grade of C) and (MATH 481 with min. grade of C or MATH 542 with min. grade of C)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 583
Wealth management and robo-advising
This course covers fundamental concepts from modern wealth management industry and design of robo-advising systems. The course builds upon Modern Portfolio Theory, CAPM and their dynamic counterparts. A significant part of the course is dedicated to analysis, modeling and practical implementation of a robo-advising system using Python and real-market data.
Prerequisite(s): MATH 474 or MATH 475
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 584
Mathematical Methods for Algorithmic Trading
This course is concerned with the design and implementation of trading strategies. In particular, it covers the mean-variance portfolio selection problem, utility maximization, pairs trading, market making, and optimal liquidation. The analysis includes such important features as: the construction and usage of predictive signals, finding a tradeoff between risk and return, accounting for transaction costs and market impact. The available mathematical tools and models are presented in each case, and they include: methods for solving constrained optimization problems, stochastic control and dynamic programming principle, time-series analysis. An important part of the course is the implementation of trading algorithms via Python, using real market data. (3-0-3)
Prerequisite(s): (MATH 481 with min. grade of C or MATH 542 with min. grade of C or MATH 543 with min. grade of C or MATH 475 with min. grade of C or MATH 474 with min. grade of C or MATH 540 with min. grade of C) and (MATH 484* or MATH 546* with min. grade of C or MATH 563* with min. grade of C or MATH 564* with min. grade of C or MATH 476* or MATH 446* or MATH 426*), An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 585
Decentralized Financial Engineering
Decentralized finance (DeFI) is one of the fastest growing areas of finance and relies on blockchains, such as Ethereum, to provide decentralized applications for financial services. The purpose of this course is to equip students with engineering knowledge of DeFI markets and the ability to create models of token behaviour (tokenomics) and market microstructure in addition to gain familiarity with the tooling for implementing smart contracts.
Prerequisite(s): MATH 584 and MATH 474
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 586
Theory and Practice of Fixed Income Modeling
The course covers basics of the modern interest rate modeling and fixed income asset pricing. The main goal is to develop a practical understanding of the core methods and approaches used in practice to model interest rates and to price and hedge interest rate contingent securities. The emphasis of the course is practical rather than purely theoretical. A fundamental objective of the course is to enable the students to gain a hands-on familiarity with and understanding of the modern approaches used in practice to model interest rate markets.
Prerequisite(s): (MATH 481* with min. grade of C or MATH 542 with min. grade of C) and (MATH 485 with min. grade of C or MATH 548 with min. grade of C), An asterisk (*) designates a course which may be taken concurrently.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 587
Theory and Practice of Modeling Risk and Credit Derivatives
This is an advanced course in the theory and practice of credit risk and credit derivatives. Students will get acquainted with structural and reduced form approaches to mathematical modeling of credit risk. Various aspects of valuation and hedging of defaultable claims will be presented. In addition, valuation and hedging of vanilla credit derivatives, such as credit default swaps, as well as vanilla credit basket derivatives, such as collateralized credit obligations, will be discussed.
Prerequisite(s): MATH 582 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 588
Advanced Quantitative Risk Management
This is an advanced course on quantitative risk management. The major concepts and ideas from the modern risk management will be explained and illustrated. The course builds upon general theory of risk measures and performance measures and addresses the current regulatory requirements for market participants.
Prerequisite(s): MATH 548 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 589
Numerical Methods for Partial Differential Equations
This course introduces numerical methods, especially the finite difference method for solving different types of partial differential equations. The main numerical issues such as convergence and stability will be discussed. It also includes introduction to the finite volume method, finite element method and spectral method. Prerequisite: An undergraduate numerical course such as MATH 350 and a PDE course such as MATH 461 or MATH 489 or consent of instructor.
Prerequisite(s): (MATH 350 or Graduate standing) and (MATH 461 or MATH 489)
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 590
Meshfree Methods
Fundamentals of multivariate meshfree radial basis function and moving least squares methods; applications to multivariate interpolation and least squares approximation problems; applications to the numerical solution of partial differential equations; implementation in Matlab.
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 591
Research and Thesis M.S.
Prerequisite: Instructor permission required.
Credit: Variable

MATH 592
Internship in Applied Mathematics
The course is for students in the Master of Applied Mathematics program who have an approved summer internship at an outside organization. This course can be used in place of Math 523 subject to the approval of the director of the program.
Credit: Variable

MATH 593
Seminar in Applied Mathematics
Current research topics presented in the department colloquia and seminars.
Lecture: 1 **Lab:** 0 **Credits:** 0

MATH 594
Professional Master's Project
The course is part of the capstone experience for students in the Master of Applied Mathematics program. Students will work in groups of 2 or 3 to study and analyze a real-world problem.
Credit: Variable

MATH 597
Reading and Special Projects
(Credit: Variable)
Credit: Variable

MATH 599
TA Training
This course provides the foundation of how to teach mathematics in the context of introductory undergraduate courses. The course is designed to encourage participation and cooperation among the graduate students, to help them prepare for a career in academia, and to help convey the many components of effective teaching.
Lecture: 1 **Lab:** 0 **Credits:** 0

MATH 601
Advanced Topics in Combinatorics
Course content is variable and reflects current research in combinatorics.
Prerequisite(s): MATH 554 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 602
Advanced Topics in Graph Theory
Course content is variable and reflects current research in graph theory.
Prerequisite(s): MATH 554 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 603
Advanced Topics in Computational Mathematics
Course content is variable and reflects current research in computational mathematics.
Prerequisite(s): MATH 578 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 604
Advanced Topics in Applied Analysis
Course content is variable and reflects current research in applied analysis.
Prerequisite(s): MATH 501 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 605
Advanced Topics in Stochastics
Course content is variable and reflects current research in stochastic.
Prerequisite(s): MATH 544 with min. grade of C
Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 691
Research and Thesis Ph.D.
(Credit: Variable)
Credit: Variable

MATH 764
Linear Regression
This is an introductory course on regression analysis. Topics include simple and multiple linear regression models, least square estimates of parameters, hypothesis testing, and confidence intervals. Students are expected to use software packages like R to analyze data.
Lecture: 1 **Lab:** 0 **Credits:** 1

MATH 765
Model Diagnostics and Remedial Measures
In this course, we will examine the situation when the assumptions of the regression model have been violated and how to remediate them.
Lecture: 1 **Lab:** 0 **Credits:** 1

MATH 766
Variable Selection, Model Validation, and Nonlinear Regression
In this course, we will examine the variable selection procedures, logistic regression and generalized linear model.
Lecture: 1 **Lab:** 0 **Credits:** 1

STAT 514
Applied Computational Statistics for Analytics
Generating actionable insights from data relies heavily on proper usage of analytics. The foundation of this process consists of two key ingredients: fundamental statistical concepts and corresponding computational tools. This course covers the topics from statistics and programming necessary to understand how such concepts come about, why the algorithms work the way they do, and how to use these in practice. The emphasis is on implementing the foundational procedures in industry-standard programming languages.
Lecture: 3 **Lab:** 0 **Credits:** 3