

MATHEMATICS (MATH)

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)]

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)]

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) OR (MATH 489)]

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.

Prerequisite(s): [(MATH 252)]

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)]

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): [(CHEM 511 and MATH 522)]

Lecture: 6 **Lab:** 0 **Credits:** 6

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 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 332) OR (MATH 532)]

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)]

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)]

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 400)]AND[(MATH 475)]

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) OR (MATH 333)]AND[(MATH 475)]

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)]

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 540)]

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) OR (MATH 543) OR (MATH 544)]

Lecture: 3 **Lab:** 0 **Credits:** 3

MATH 546**Introduction to Time Series**

Properties of stationary, random processes; standard discrete parameter models, autoregressive, moving average, harmonic; standard continuous parameter models. Spectral analysis of stationary processes, relationship between the spectral density function and the autocorrelation function; spectral representation of some stationary processes; linear transformations and filters. Introduction to estimation in the time and frequency domains.

Prerequisite(s): [(ECE 511) OR (MATH 475)]

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) OR (MATH 475)]

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)]

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, Turan-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)]

Lecture: 3 Lab: 0 Credits: 3

MATH 554**Discrete Applied Mathematics II**

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) OR (MATH 553)]

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 and MATH 400)]

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)]

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 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. Credit given only for one of MATH 425, MATH 476, MATH 525, or MATH 563.

Prerequisite(s): [(MATH 475)]

Lecture: 3 Lab: 0 Credits: 3

MATH 564**Applied Statistics**

Simple linear regression; multiple linear regression; least squares estimates of parameters; hypothesis testing and confidence intervals in linear regression models; testing of models, data analysis, and appropriateness of models; linear time series models; moving average, autoregressive and/or ARIMA models; estimation, data analysis, and forecasting with time series models; forecasting errors and confidence intervals. Credit may not be granted for both MATH 484 and MATH 564.

Prerequisite(s): [(MATH 474) OR (MATH 476) OR (MATH 563)]

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)]

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, MATH 563, and MATH 564)]

Lecture: 3 Lab: 0 Credits: 3

MATH 567**Advanced Design of Experiments**

Various type of designs for laboratory and computer experiments, including fractional factorial designs, optimal designs and space filling designs.

Prerequisite(s): [(MATH 474) OR (MATH 476)]

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)]

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 350)]AND[(MATH 474) OR (MATH 475)]

Lecture: 3 Lab: 0 Credits: 3

MATH 570**Data Science Seminar**

Various research topics on data science are presented in this seminar. Permission is required from the instructor or department.

Lecture: 0 Lab: 0 Credits: 0

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.

Prerequisite(s): [(CSP 570*) OR (MATH 570*)]An asterisk (*) designates a course which may be taken concurrently.

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): [(CSP 571) OR (MATH 571)]AND[(SCI 522)]

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 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)]

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)]

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)]

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 400)]

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 481) OR (MATH 542)]AND[(MATH 485) OR (MATH 548)]

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 hand-on familiarity with and understanding of the modern approaches used in practice to model interest rate markets.

Prerequisite(s): [(MATH 485 and MATH 582*) OR (MATH 543 and MATH 582*)]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)]

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 MATH 489 or consent of instructor.

Prerequisite(s): [(MATH 350 and 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.

Lecture: 0 Lab: 0 Credits: 6

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)]

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)]

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)]

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)]

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)]

Lecture: 3 Lab: 0 Credits: 3

MATH 691

Research and Thesis Ph.D.

(Credit: Variable)

Credit: Variable