Mathematics (MATH)

MATH 1001 Pre-Calculus 3 Credits
This course is intended as a preparation for MATH-1350: Calculus I. Topics include: algebraic operations, factoring, exponents and logarithms, polynomials, rational functions, trigonometric functions, inverse trigonometric functions, and the logarithmic and exponential functions.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 1004 Mathematics in Society 3 Credits
The course provides an overview of mathematical concepts as they relate to various disciplines. Topics will be chosen from set theory, logic, combinatorics, probability, statistics, and voting theory. It is a course for students who require a general overview of mathematics, especially those majoring in liberal arts, the social sciences, business, nursing and allied health fields. This course is not designed to prepare students for any specific future mathematics course. This course meets the Quantitative Reasoning and Data Literacy (QRDL) core requirement.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 029

MATH 1040 Probability and Statistics 0 or 4 Credits
This course will introduce students to the basic concepts, logic, and issues involved in statistical reasoning, as well as basic statistical methods used to analyze data and evaluate studies. The major topics to be covered include methods for exploratory data analysis, an introduction to sampling and experimental design, elementary probability theory and random variables, and methods for statistical inference including simple linear regression. The objectives of this course are to help students develop a critical approach to the evaluation of study designs, data and results, and to develop skills in the application of basic statistical methods in empirical research. An important feature of the course will be the use of statistical software to facilitate the understanding of important statistical ideas and for the implementation of data analysis. College Economics and Political Economy majors should enroll in ECON 2110 or MATH 2140. This course does NOT count towards a mathematics credit. Mathematics majors/minors and Statistics minors should enroll in MATH 2140. Seniors and Post Baccalaureate Pre-Medical students must get special permission to enroll in this course.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)
Mutual exclusion: IPOL 3270, BSFS 3200, INAF 3200

MATH 1310 Calculus with Review A 3 Credits
MATH-031 is the first course of a year-long sequence that covers the material in a Calculus I course. This year-long sequence is appropriate for students who do not have a strong precalculus/algebra background. Only students who get a score between 40 and 75 on the Calculus Readiness Assessment are allowed to enroll in MATH-031. Students enroll in MATH-031 in the Fall semester and continue on to take MATH-032 (Calculus with Review B) the Spring semester. This allows the students and the professor to pace through the Calculus I concepts over the period of a full year. MATH-031 begins with a refresher of some important concepts related to functions, progressing into a study of limits, the conceptual underpinning of calculus, and then into differentiation. The year-long pace allows topics from algebra and precalculus to be reviewed as needed. Applications will be introduced to deepen the students' understanding of the concepts. NOTE: MATH-031 does not satisfy the College general education requirement in mathematics. Credit in MATH-031 is regarded as a free elective towards the College degree.
Level: Undergraduate
Prerequisites: A27 with a score of 40
Grading: Main Campus (UGrad, Grad)

MATH 1320 Calculus with Review B 4 Credits
MATH-032 is the second course of a year-long sequence that covers the material in a Calculus I course. MATH-032 picks up where MATH-031 left off. Topics to be covered include techniques of differentiation, applications of the derivative, the Riemann integral, the trigonometric and inverse trigonometric functions, and the logarithmic and exponential functions. After completion of Math-032, students will be able to move on to the other courses in the calculus sequence (MATH-036 and 137-150) for mathematics and science majors. NOTE: MATH-032 satisfies the College general education requirement-- see College Undergraduate Bulletin general education requirements section to see how MATH-032 can be combined in various ways to meet the math/science requirement in full.
Level: Undergraduate
Prerequisites: (MATH 031 or MATH 1310)
Grading: Main Campus (UGrad, Grad)

MATH 1350 Calculus I 4 Credits
This course is an introduction to single variable calculus. It covers calculus of single variable functions, limits, continuity, derivatives, Mean Value Theorem, applications of the derivative, L'Hôpital's Rule, antiderivatives, Riemann sums, the indefinite and definite integral, basic techniques of integration, and the Fundamental Theorem of Calculus. In this course, students review and extend their knowledge of the exponential, logarithmic, trigonometric, and inverse trigonometric functions.
Level: Undergraduate
Course attribute:
Grading: Main Campus (UGrad, Grad)
Mutual exclusion: MATH 1320, MATH 1310, MATH 032, MATH 031, MATH 029

MATH 1360 Calculus II 4 Credits

This is the second course in the Calculus sequence and is a continuation of MATH-1350. Topics include techniques of integration, applications of the definite integral, improper integrals, sequences and series including Taylor's theorem and power series, and polar and parametric curves.

Level: Undergraduate

Prerequisites: MATH 1350 or MATH 1320 or APMA with a score of 5 or APMB with a score of 4

Grading: Main Campus (UGrad, Grad)

Mutual exclusion:

MATH 1505 Data Visualization Graphics 3 Credits

Prerequisites: Any introductory statistics course, MATH 1040, ECON 2110, GOV 2201, IPOL 3270, MATH 2140, OPAN 2101, or AP Statistics score of 5. Description: Effective graphical displays of data allow the viewer to understand the structure of a complex dataset at a glance. Graphical displays have many purposes from an initial exploration of a dataset to presentation of final results. This course provides an introduction to using the statistical software package R to create appropriate and illuminating visual displays of data. Properties that make a visual display of data clear, accurate, and powerful will be discussed and tools to create effective visualizations will be taught. In addition, students will learn some of the most common abuses of data visualization and how to recognize (and correct) misleading displays of data. The course has a final project component where students will need to present and defend their results. Classroom material will be accompanied by hands-on experience using statistical software.

Level: Undergraduate

Prerequisites: (MATH 040 or MATH 1040) or MATH 104X or (MATH 140 or MATH 2140) or (ECON 121 or ECON 2110) or (INAF 320 or INAF 3200) or (IPOL 320 or IPOL 3270) or (OPIM 170 or OPAN 1101) or (OPIM 172 or OPAN 2102) or (OPIM 173 or OPAN 2101) or (GOVT 201 or GOVT 2201) or MATH 04-

Grading: Main Campus (UGrad, Grad)

Mutual exclusion: MATH 225

MATH 1510 Intro Programming for Data Sci 3 Credits

Prerequisite: MATH 1350 Description: Programming, writing computer code, is an essential component of the analysis of data. This course will teach students the basic programming concepts needed to work with and analyze data. The class will be taught using the R programming language. No previous programming experience is needed. Basic programming concepts will be covered as well as fundamental data analysis paradigms. UNIX scripting, version control through git, and research reproducibility through knitr will be covered. Plotting and visualization will be covered through the ggplot R package.

Level: Undergraduate

Prerequisites: (MATH 035 or MATH 1350)

Grading: Main Campus (UGrad, Grad)

MATH 2010 Graph Theory 3 Credits

This course covers types of graphs such as trees, networks, Eulerian and Hamiltonian graphs, tournaments and DAGS. Properties such as planarity, bipartiteness, and connectivity are related. We consider vertex and edge colorings of graphs and graph drawings with applications to VLSI chips, RNA folding, and traffic signal design.

Level: Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 2020 Combinatorics 3 Credits

Main topics in the course include permutations and combinations, recurrence relations, and the Principle of Inclusion/Exclusion with applications to counting derangements and surjections. We also cover the 12-fold way, the Robinson-Schensted correspondence, Latin Squares and the Euler conjecture, design theory, and projective planes.

Level: Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 2110 Scientific Computing 3 Credits

Scientific computing describes a broad array of techniques and ideas used to implement mathematical and statistical algorithms on a computer. In this class, we will focus on the application of computing to data analysis. We will explore theory and algorithms that underlie regression, classification, clustering, and dimension reduction. A particular emphasis will be placed on numerical optimization, one of the main pillars of scientific computing. As the course progresses, we will find that implementation of many algorithms will depend on numerically solving, that is on a computer, some basic problems from linear algebra and calculus, leading us to cover some key ideas in numerical analysis and numerical linear algebra. Programming in R will be an essential component of the course, although no previous programming experience is needed.

Level: Undergraduate

Prerequisites: (MATH 137 or MATH 2370) and (MATH 150 or MATH 2250)

Grading: Main Campus (UGrad, Grad)

MATH 2140 Intro Math Statistics 3 Credits

This course provides an introduction to probability theory and statistical inference. The first half of the course introduces fundamentals in probability. Topics to be covered include basic probability principles, enumeration methods, properties of random variables, common discrete and continuous distribution functions, and expected values. The second half of the course focuses on the core of statistical inference and deals with the central limit theorem, maximum likelihood estimation, confidence intervals, hypothesis testing, and the linear regression model. Statistical software will be used to illustrate concepts and to perform data analysis.

Level: Undergraduate

Prerequisites: MATH 1360 or MATH 036 or CALC with a score of 3 or APMB with a score of 5

Grading: Main Campus (UGrad, Grad)

Mutual exclusion: ANLY 511, DSAN 5100, ECON 121, ECON 2110

MATH 2240 Math for Machine Learning 4 Credits

Prerequisite: MATH 1360

Description: This course is designed to lay a strong mathematical foundation for students who wish to pursue AI or Data Science related topics. The course will cover matrix algebra, differentiation of functions of many variables, integration on high dimensional domains, basic problems of machine learning, such as linear regression, and the use of continuous optimization to solve them. Students will gain insight into why modern tools like Large Language Models (LLM) work or fail in different circumstances. This course is suitable for math majors, math/statistics minors, as well as students from other departments.

Level: Undergraduate

Prerequisites: MATH 1360

Grading: Main Campus (UGrad, Grad)

MATH 2250 Linear Algebra 4 Credits
This course presents the basic theory and methods of finite dimensional vector spaces and linear transformations on them. Topics include: matrices and systems of linear equations; vector spaces, bases, and dimension; linear transformations, kernel, image, matrix representation, basis change, and rank; scalar products and orthogonality; determinants, inverse matrices; eigenvalues, eigenvectors, diagonalization of symmetric matrices, positive definite matrices, spectral theorem for Hermitian matrices; linear discrete dynamical systems via matrix iteration.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)
Mutual exclusion: ECON 1357

MATH 2370 Multivariable Calculus 4 Credits
Prerequisite: MATH 1360 or equivalent Description: This is a first course in differential and integral calculus of functions of several variables. After the introduction of vectors and the 2 and 3-dimensional Euclidean space, functions of several variables are discussed. Functions of two variables will be visualized by surfaces in the three-dimensional space. Partial derivatives and the total derivative of real-valued and vector-valued functions, the chain rule, directional derivatives, extrema of real-valued functions, constrained extrema and Lagrange multipliers, and double and triple integrals will be covered. Time permitting, the course will conclude with fundamental theorems of vector calculus, including Green’s, Gauss’s, and Stokes’s theorems.
Level: Undergraduate
Prerequisites: (MATH 036 or MATH 1360)
Grading: Main Campus (UGrad, Grad)
Mutual exclusion:

MATH 2410 Ordinary Differential Equation 3 Credits
This course provides an introduction to the theory, techniques, and applications of ordinary differential equations. Topics include first order equations, second order linear equations, series solutions, the method of Laplace transforms, systems of equations, Euler’s Method, some bifurcation theory, an introduction to nonlinear equations and stability theory.
Level: Undergraduate
Course attribute:
Grading: Main Campus (UGrad, Grad)

MATH 2420 Discrete Dynamical Systems 3 Credits
This course is an introduction to the mathematical theory of discrete dynamical systems, in which the state of a changing system at a given time is a fixed function of the previous state, and the long term behavior of the system is determined by iterating (i.e. self-composing) the function over and over. This theory is used to analyze ecological models, financial processes, differential equations, and more, and also illustrates how a system with seemingly simple rules can lead to surprisingly complicated behavior. In this course we'll cover the following topics in one-dimensional dynamics: fixed point analysis, bifurcation theory, the quadratic family, chaotic systems, symbolic dynamics, Sharkovsky's theorem, and an introduction to fractals and complex dynamics. The focus of the course will be on theory supplemented by computational experimentation.
Level: Undergraduate
Prerequisites: MATH 2370 and MATH 2250
Grading: Main Campus (UGrad, Grad)

MATH 2430 Convex Geometry, Func. App. 3 Credits
Convexity is an important concept in advanced mathematics, with important applications to optimization, economics, materials science, and other fields. In this elementary introduction, we will study convex sets, hyperplanes, linear functionals, separating hyperplanes, supporting hyperplanes, Helly's Theorem, Kirchberger's Theorem, the isoperimetric problem, polytopes, Euler's formula, convex duality, linear programming, convex functions, distance functions, continuity and differentiability properties of convex functions, and optimization and convexity. We will consider examples taken from optimization, economics and materials science.
Level: Undergraduate
Prerequisites: (MATH 137 or MATH 2370) and (MATH 150 or MATH 2250)
Grading: Main Campus (UGrad, Grad)

MATH 2460 Intro to Mathematical Biology 3 Credits
Mathematical and statistical techniques are central to biology today. This course examines applications of mathematics in biological contexts including genetics, ecology, physiology, neuroscience and epidemiology. It draws on diverse mathematical tools and introduces students to principles that underlie mathematical modeling in diverse scientific and technical domains.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 2490 Nonlinear Differentl Equations 3 Credits
Nonlinearity is one of the major themes of modern mathematics, with applications in virtually every field. This course introduces key concepts of nonlinear dynamics through ordinary differential equations, preparing students for applied work in physics, biology, economics and many other fields, as well as for graduate-level study of dynamical systems. Topics include flows on the line, circle, plane and torus; limit cycles; bifurcations of one- and two-dimensional systems; and chaos.
Level: Undergraduate
Prerequisites: (MATH 137 or MATH 2370) and (MATH 150 or MATH 2250)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Undergraduate level students.

MATH 2540 Regression Analysis 3 Credits
This course provides an in-depth coverage of regression analysis. After reviewing matrix algebra and simple linear regression using matrix notation, the course will focus on inference and model building in multiple linear regression. Regression inference, handling of categorical regressors, variable selection, interaction effects, multicollinearity, model diagnostics will be thoroughly covered. The course concludes with one-way and multi-way analysis of variance (ANOVA) models. Statistical concepts will be accompanied by hands-on data analysis using the R statistical software.
Level: Undergraduate
Prerequisites: (MATH 140 or MATH 2140) or (ECON 121 or ECON 2110)
Grading: Main Campus (UGrad, Grad)
Mutual exclusion: PSYC 5004, PSYC 521

MATH 2620 Statistical Learning DataSci 3 Credits

This course will introduce students to tools for handling large, heterogeneous datasets. Topics to be discussed include data visualization, data analysis using statistical and machine learning methods, and interpretation and communication of results. We will cover dimension reduction techniques (SVD, PCA), unsupervised clustering methods (k-means, hierarchical), supervised learning methods (linear regression, logistic regression, k-nearest neighbor, classification and regression trees, random forests, support vector machines), performance evaluation (bias-variance trade-off, cross-validation), variable selection methods (shrinkage methods, variable importance). The R statistical software will be used.

Level: Undergraduate

Prerequisites: MATH 2540 or MATH 240 or ECON 2120 or ECON 122

Grading: Main Campus (UGrad, Grad)

MATH 2625 Biostatistical Methods 3 Credits

This course introduces students to some of the basic statistical techniques used in the analysis of data resulting from biomedical and biological research. Data from these sources can often have small samples, be categorical, or include time-to-event outcomes. Consequently, we will cover the derivation and application of introductory methods for nonparametric statistics, contingency tables, and survival analysis. Topics include signed rank tests, rank sum tests, the delta method, exact tests, Pearson's chi-squared test, risk ratios, various odds ratio estimators, survivor and hazard functions, Kaplan-Meier and Nelson-Aalen estimators, log-rank tests, and multiple testing adjustments. This course emphasizes the writing up and presentation of statistical results for consumption by a broader audience. Statistical computing is performed using the statistical freeware tool, R.

Level: Graduate, Undergraduate

Prerequisites: (MATH 140 or MATH 2140) or (ECON 121 or ECON 2110)

Grading: Main Campus (UGrad, Grad)

MATH 2640 Advanced Regression Methods 3 Credits

This course expands on the concepts learned in Math-2540 and introduces students to advanced regression methods. We will start with a review of linear regression models, including model building and model diagnostics. The course will focus on generalized linear models (GLM) for non-Gaussian response data, including models for categorical outcomes (logistic, multinomial logit, proportional odds models) and models for count data (Poisson, negative binomial, zero-inflated models). If time permits, other advanced topics chosen by the instructor will be discussed. Statistical concepts will be accompanied by hands-on data analysis using the R statistical software.

Level: Undergraduate

Prerequisites: MATH 240 or MATH 2540 or PSYC 5004 or PSYC 521 or ECON 2120 or ECON 122 or ECON 3001

Grading: Main Campus (UGrad, Grad)

MATH 2645 Applied Time Series Analysis 3 Credits

This course introduces students to the theory and application of time series methods for data that are collected over time. Topics include exploratory data analysis tools, methods for detrending, and seasonal adjustment of data, regression methods including regression with autoregressive errors, smoothing techniques including exponential smoothing, modeling and forecasting based on the ARIMA class of models, and ARCH/GARCH models. Time permitting, advanced topics including neural network methods for time series, and methods for analyzing multivariate time series. Students gain hands-on experience of applied time series methods for real data sets using the statistical software, R. Examples will be drawn from a variety of disciplines including business, finance, economics, health, environmental studies, and ecology. Students are required to complete a final data analysis project in which they apply the knowledge they gained in the course to real data.

Level: Undergraduate

Prerequisites: (MATH 140 or MATH 2140) or (ECON 121 or ECON 2110)

Grading: Main Campus (UGrad, Grad)

MATH 2650 Computational Statistics 3 Credits

Prerequisites: MATH 2140 or ECON 2110.

Description: Modern statistics increasingly relies on computationally intensive methods and techniques. This course introduces students to some of those commonly used methods. It assumes knowledge of concepts from introductory mathematical statistics including probability distributions, expectations, maximum likelihood estimation, and hypothesis testing. While some familiarity with the open source software R is preferred, no prior programming experience is expected. Topics will include random number generation, deterministic methods like Fisher scoring, rejection sampling, importance sampling, permutation tests, jackknifing, cross validation, bootstrap resampling, elementary Bayesian statistics, Gibbs sampling, as well as the expectation-maximization (EM) algorithm and variational inference. All computation will be performed in R.

Level: Undergraduate

Prerequisites: MATH 2140 or ECON 2110

Grading: Main Campus (UGrad, Grad)

MATH 2700 Mathematics for Deep Learning 3 Credits
This course will explore different deep learning architectures and their associated mathematics. The architectures we will consider are fully connected neural nets, convolutional neural nets, recurrent neural nets and transformers. Associated with these architectures, we will explore basic ideas in optimization including gradient methods applied to convex and nonconvex optimization, the role of convolution in signal processing, basic models of time series, and probabilistic models in high dimensional spaces. There will likely be some variation from this plan depending on student interest and time constraints. Application of the architectures to datasets will be done through the python package Pytorch. By the end of the course, students should be able to write python code to implement the architectures. However, we will strike a balance between application and theory. By the end of the course, students should be familiar with associated ideas and results in mathematics, particularly relating to computation and modeling in high dimensions. Students who are mainly interested in implementation of the architectures are likely better off taking some of the other neural net classes offered at Georgetown.
Level: Undergraduate
Prerequisites: (MATH 2250 or MATH 150) and (MATH 2370 or MATH 137)
Grading: Main Campus (UGrad, Grad)

MATH 2800 Intro to Proof/Prob-Solving 3 Credits
This course is designed to help students transition from the computational concepts covered in 1000-level courses to the more theoretical concepts covered in 3000-level courses. Students learn to manipulate abstract definitions, determine whether statements are true or not, and prove or disprove statements. Special emphasis is placed on learning to read, write, and critique proofs. The different techniques covered are backward/forward proof, proof by contradiction, proof by contraposition, and proof by induction. Students will apply these methods to a variety of problems involving numbers, functions, sets, relations, and cardinality. This course is a prerequisite for many upper level mathematics courses.
Level: Undergraduate
Prerequisites: (MATH 036 or MATH 1360)
Course attribute:
Grading: Main Campus (UGrad, Grad)

MATH 2900 History of Mathematics 3 Credits
This course explores the evolution of mathematical ideas from ancient civilizations—Babylon, Egypt, and Greece—through major developments in India, the Islamic world, and Europe, leading to modern mathematics. Topics include arithmetic, geometry, algebra, and calculus, with emphasis on how these concepts developed within their cultural, social, and technological contexts. Students will examine historical approaches to solving familiar problems in order to deepen their understanding of foundational mathematical ideas. MATH 2800 or permission of instructor
Level: Undergraduate
Prerequisites: MATH 2800
Grading: Main Campus (UGrad, Grad)

MATH 3200 Number Theory Cryptography 3 Credits
This course begins with a survey of cryptography from Roman times up to today's high tech world. Students will learn how to encrypt messages and how to attempt to break codes. We will discuss the efficiency and security level of different encryption methods. To make the discussion rigorous, we will need tools/concepts/results from mathematics.

Mathematical content: mappings and inverse mappings, modular arithmetic, the additive group Z/n, the multiplicative group Z*/n, Euler's phi function, Fermat's Little theorem and Euler's generalization, primitive roots, discrete logarithms, Diophantine equations, the Chinese Remainder Theorem, Wilson’s theorem, multiplicative functions, quadratic residues and the law of quadratic reciprocity.

Cryptographic content: classical ciphers and their decryption (shift, affine, and Vigenere ciphers), key exchange protocols (eg, Diffie-Hellman), public key ciphers (eg, RSA).
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 3210 Abstract Algebra I 3 Credits
This is a rigorous introduction to algebraic structures, particularly groups, rings, and fields, and their homomorphisms, with emphasis on proofs. Topics from group theory will include modular arithmetic, symmetry groups, permutation groups, group actions, and Sylow theory. Topics from ring theory will include integral domains, unique factorization domains, and polynomial rings.
Level: Undergraduate
Prerequisites: (MATH 200 or MATH 2800)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics (AB), Mathematics (AB), Mathematics (AB), Mathematics (AB), Mathematics (BS), Mathematics (BS), Mathematics (BS), Mathematics (BS), Mathematics, Mathematics, Mathematics or Mathematics.

MATH 3300 Differential Geometry 3 Credits
This course discusses the geometry of curves and surfaces.
The length and the curvature of a smooth curve in two and three dimensions will be defined and computed. Parametrized surfaces in three-dimensional space are introduced and analyzed. Examples of quadric surfaces and ruled surfaces are presented. Important concepts are the Gauss curvature and Mean curvature of surfaces. Finally the inner geometry of surfaces is discussed and the concept of a geodesic, which is a curve on a surface that minimizes the distance between two points, is introduced. If time permits some theorems of vector calculus that you may have seen in Multivariable Calculus are reviewed. This course will reinforce tools studied in Multivariable Calculus, such as the chain rule, as well as elements of Linear Algebra, in particular the Spectral Theorem.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 3310 Analysis I 3 Credits
This is the first part of the two semester advanced calculus sequence (MATH 3310 & MATH 4310) which provides a rigorous treatment of topics in calculus with the emphasis on proofs of major theorems. Topics include the basic properties of the real numbers and n-dimensional Euclidean space, the basic topology of metric spaces including compactness and connectedness, the theory of numerical sequences and series, and the properties of continuous functions, differentiable functions and integrable functions on the real line.
This course is expected to result in an appreciation of some of the central theorems of analysis on the real line, such as the Mean Value Theorem, Inverse Function Theorem and Taylor's formula.
Level: Undergraduate
Prerequisites: (MATH 200 or MATH 2800)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics (AB), Mathematics (AB), Mathematics (AB), Mathematics (AB), Mathematics (BS), Mathematics (BS), Mathematics (BS), Mathematics (BS), Mathematics, Mathematics, Mathematics or Mathematics.

MATH 3320 Functions of Complex Variables 3 Credits
Complex numbers. Analytic functions including exponential, logarithmic and trigonometric functions of a complex variable. Geometric and mapping properties of analytic functions. Contour integration, Cauchy's theorem, the Cauchy integral formula. Power series representations. Residues and poles, with applications to the evaluation of integrals. Conformal mapping and applications as time permits.
Level: Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)

MATH 3960 Putnam Seminar 1 Credit
This seminar, which is open to all undergraduates, will prepare students to take the William Lowell Putnam Mathematical Competition. The seminar will cover topics ranging from general problem-solving techniques to field-specific results and methods. Students enrolling in the seminar will be expected to participate in the Putnam Competition.
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 4100 Nonlinear Algebra 3 Credits
This course is about nonlinear algebra, which is as applicable and powerful as linear algebra. It has applications in areas as diverse as optimization, cryptography, computer graphics and statistics. Nonlinear algebra deals with systems of polynomial equations of various degrees (known as "ideals") and their solution sets (known as "algebraic varieties"). We will learn how to use computational algorithms to investigate and connect these objects. Topics covered will include basics of algebraic structures, generating sets for ideals known as Grobner bases (similar to bases of vector spaces), and algorithms to compute such bases (Buchberger's algorithm). This course will involve the use of computer algebra systems like SageMath or Macaulay2. These are powerful free software systems that are capable of algebraic computations, among many other things. No previous programming experience is assumed.
Level: Graduate, Undergraduate
Prerequisites: MATH 2800 and MATH 2250
Grading: Main Campus (UGrad, Grad)

MATH 4110 Topology 3 Credits
This course serves as an introduction to topology, both point-set topology and algebraic topology. The first half of the course is devoted to the basics of point-set topology. Topics include topological spaces, basis for a topology, metric spaces, subspaces, product spaces, continuous maps and homeomorphisms, connectedness and path-connectedness, compactness, the Cantor set, quotient spaces, and surfaces. The remainder of the course explores some aspects of algebraic topology: homotopy and homotopy type, cell complexes, operations on spaces, homotopy equivalence, the fundamental group and its applications, Van Kampen's theorem, and covering spaces.
Level: Graduate, Undergraduate
Prerequisites: (MATH 215 or MATH 3210)
Grading: Main Campus (UGrad, Grad)

MATH 4200 Nonlinear Algebra 3 Credits
This course is about nonlinear algebra, which is as applicable and powerful as linear algebra. It has applications in areas as diverse as optimization, cryptography, computer graphics and statistics. Nonlinear algebra deals with systems of polynomial equations of various degrees (known as "ideals") and their solution sets (known as "algebraic varieties"). We will learn how to use computational algorithms to investigate and connect these objects. Topics covered will include basics of algebraic structures, generating sets for ideals known as Grobner bases (similar to bases of vector spaces), and algorithms to compute such bases (Buchberger's algorithm). This course will involve the use of computer algebra systems like SageMath or Macaulay2. These are powerful free software systems that are capable of algebraic computations, among many other things. No previous programming experience is assumed.
Level: Graduate, Undergraduate
Prerequisites: MATH 2800 and MATH 2250
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4100

MATH 4210 Abstract Algebra II 3 Credits
This course will cover rings and their homomorphisms, ideals, prime and maximal ideals, Euclidean domains, principal ideal domains, unique factorization domains, polynomial rings, irreducibility criteria for polynomials, and Galois theory as much as time permits: fields and their extensions, splitting fields, separable and normal extensions, automorphism groups of fields, Galois extensions and modules.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 4255 GenderCare in Mod. US Poetry 3 Credits
TBD
Level: Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 4307 Mathematics of Climate 3 Credits

In this course, mathematics and statistics will be used to answer current questions of interest in climate science and sustainability, and climate science will be used to motivate and explain techniques from applied mathematics and statistics. Mathematical and statistical topics will be selected from theories and methodologies for dynamical systems, bifurcation theory, ordinary and partial differential equations, signal processing, regression analysis, extreme value theory, and data assimilation. The course will emphasize conceptual models that capture important aspects of the Earth's climate system: Energy balance and temperature distribution, ocean circulation patterns such as the Gulf Stream and El Niño – Southern Oscillation, glaciation cycles, extreme weather events, and data assimilation for weather and climate. Some knowledge of R is required.

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 4310 Analysis II 3 Credits

Prerequisite: MATH 3310. Description: This course is about analysis in n-dimensional Euclidean spaces. Topics include the Euclidean spaces, metric spaces, functions of several variables, differentiation and integration of functions of several variables, and the theorems of vector calculus. Most of the topics will be familiar from Multivariable Calculus (MATH-2370). Many proofs will be presented and discussed. Students will be made familiar with some concepts of topology, the basic theory of metric spaces as well as the importance of compact sets and connected sets in analysis. This course is expected to result in an appreciation for some of the central theorems of analysis such as the Inverse and Implicit Function Theorems, the Change of Variable Formula in multiple integrals, and the Integral Theorems by Green, Gauss, and Stokes.

Level: Graduate, Undergraduate

Prerequisites: (MATH 310 or MATH 3310)

Grading: Main Campus (UGrad, Grad)

MATH 4311 Intro Partial Diff Equations 3 Credits

Partial differential equations are essential tools in applied mathematics. This course synthesizes and builds upon techniques and concepts from multivariable calculus, linear algebra and ordinary differential equations to solve and analyze key linear partial differential equations such as the Laplace equation, the heat equation, and the wave equation. Topics include initial and boundary value problems, maximum principles, Fourier series, Fundamental solutions and Green functions.

Level: Graduate, Undergraduate

Prerequisites: (MATH 137 or MATH 2370) and (MATH 150 or MATH 2250)

Grading: Main Campus (UGrad, Grad)

MATH 4314 Optimization 3 Credits

Optimization problems arise in a variety of applied sciences. Examples are the most economical transport of goods from service points to destinations, the design of components in manufacturing, or the desire to minimize noises and vibrations in airplanes or cars. The mathematical formulation of optimization problems results in the task of minimizing or maximizing functions which are subject to additional conditions called constraints. Some optimization problems, such as finding the extreme values (maxima and minima) of continuous functions of several variables, are already discussed in calculus. Of particular interest in this course are optimization problems with constraints, possibly given by additional equations, inequalities, or differential equations. According to the type and the nature of the constraint, different techniques of solving the optimization problem are to be developed. These include linear programming, nonlinear programming, variational problems, and optimal control. Students will see a good number of examples of optimization problems, study various analytical techniques of solving them, reinforce their knowledge of differential calculus of functions of several variables, and should gain an appreciation of two fundamental mathematical concepts: Linearity and Convexity.

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 4320 Intro Stoch Diff Equations 3 Credits

Many real-world systems, from finance to physics to neuroscience, exhibit random behavior that can be modeled using stochastic differential equations (SDEs). This course provides a first introduction to SDEs. After reviewing some essential probability theory, we construct and analyze Brownian motion. We then develop Itô’s integral, including the chain and product rules. Finally, we study Itô SDEs, examining existence and uniqueness of solutions and exploring applications to partial differential equations and option pricing.

Level: Graduate, Undergraduate

Prerequisites: MATH 2410 and (MATH 2140 or ECON 2110) and (MATH 2240 or MATH 2250)

Grading: Main Campus (UGrad, Grad)

Equivalent to MATH 3320

MATH 4460 Machine Learning: Theory App 3 Credits

Machine Learning describes a collection of computational techniques for finding patterns in data. This course focuses on supervised machine learning, which deals with using historical labeled data to construct a predictor to accurately label future data. We will cover how to formulate the supervised learning problem in mathematical terms, describe a measure of performance, restrict a search space for constructing models for prediction, optimize performance over the search space, and check for generalization. We will also discuss statistical learning guarantees and of the limits in such results. The course, while theory-centric, will provide substantive exposure to implementation through programming exercises, and will establish foundations for constructing architectural ingredients of neural networks, which are ubiquitous in modern machine learning practice.

Level: Graduate, Undergraduate

Prerequisites: (MATH 2140 or MATH 140) and (MATH 2250 or MATH 150) and (MATH 2370 or MATH 137) or MATH 5051

Grading: Main Campus (UGrad, Grad)

MATH 4531 Real Analysis 3 Credits
Measure theory, Lebesgue integral, L^p spaces, duality, representation theorems, Radon- Nikodym and Fubini theorem, differentiation of integrals, a few facts from harmonic analysis.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)

MATH 4532 Advanced Linear Algebra 3 Credits
Rigorous treatment of vector and inner product spaces, LU factorization, QR factorization, spectral theorem and singular value decomposition, Jordan form, positive definite matrices, quadratic forms, partitioned matrices, and norms and numerical issues, Hilbert spaces, compact operators, diagonalization of self-adjoint compact operators, Fredholm alternative.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 8110

MATH 4533 Numerical Analysis 3 Credits
Machine arithmetic, linear systems, root finding, interpolation and quadrature, eigenvalue problems, and ordinary differential equations.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)

MATH 4534 Complex Analysis 3 Credits
This is a PhD-level course that rigorously covers core topics in classical complex analysis. These topics include: analytic functions; harmonic functions; the Schwarz lemma; contour integration; conformal mapping; the Riemann mapping theorem; the Mittag-Leffler theorem; analytic continuation. This class provides preparation for the complex analysis portion of the Comprehensive Exam. Instructor approval required.
Level: Graduate, Undergraduate
Prerequisites: MATH 3310 and MATH 4110 or MATH 4531
Grading: Main Campus (UGrad, Grad)

MATH 4535 Probability 3 Credits
A measure-theoretic introduction to probability. Topics will include definition of probability spaces and associated analytic tools, law of large numbers, central limit theorems, martingales, ergodic theorems, and diffusions. Time permitting, computational methods associated with probability will be introduced.
Level: Graduate, Undergraduate
Prerequisites: MATH 4531
Grading: Main Campus (UGrad, Grad)

MATH 4536 Computational Mathematics 3 Credits
This is a PhD level course. This course will survey key elements of computational mathematics with a particular emphasis on methods applicable to data. Course topics will include optimization, matrix analysis and approximation, graphs and networks, and linear and non-linear methods in dimension reduction and function approximation. An emphasis will be placed on computation in high dimensions and associated theory. Students who lack a working knowledge of a scripting language such as R or Python are welcome, but should talk to the instructor prior to taking the course.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 4540 Functional Analysis 3 Credits
This is a PhD level course.

Hilbert spaces, Banach spaces, convergence in topological vector spaces, dual spaces, Riesz representation theorem, Theorem of Hahn-Banach, open mapping theorem, closed graph theorem, principle of uniform boundedness, spectral theorem for (un)bounded operators, semigroups of linear operators, Fredholm operators, and Fredholm index.
Level: Graduate, Undergraduate
Prerequisites: MATH 471 and (MATH 472 or MATH 4532 or MATH 5032)
Grading: Main Campus (UGrad, Grad)

MATH 4541 Partial Differential Equation 3 Credits
Linear and nonlinear first-order PDE, Sobolev spaces, distributions, Fourier transform, linear elliptic, parabolic, and hyperbolic equations, initial value problems, and boundary value problems.
Level: Graduate, Undergraduate
Prerequisites: MATH 471 and (MATH 480 or MATH 5040 or MATH 4540) and (MATH 401 or MATH 5035 or MATH 4535)
Grading: Main Campus (UGrad, Grad)

MATH 4542 Selected Topics in PDE 3 Credits
This is a PhD level course.

This course is a continuation of MATH 4541. Topics include Nonlinear first-order PDE, the method of characteristics, Hamilton-Jacobi equations, conservation laws, Fourier transform, Laplace transform, and the Radon transform. In the context of similarity solutions plane waves, traveling waves, solitons, group velocity, and phase velocity will be introduced. The method of stationary phase will be discussed in the context of asymptotic solutions. Solutions based on power series and the Cauchy-Kovalevskaya Theorem are studied. The course concludes with the study of semigroups of linear operators. The method of semigroup will be applied to various linear and some non-linear equations and produce strong existence, uniqueness, and stability results.
Level: Graduate, Undergraduate
Prerequisites: MATH 4541
Grading: Main Campus (UGrad, Grad)

MATH 4543 Riemannian Geometry 3 Credits
This is a PhD-level course. Riemannian Geometry is a second course in Differential Geometry. This course will cover differentiable manifolds, Riemannian metrics, affine and Riemannian connections, geodesics and their minimizing properties, sectional curvature, Ricci curvature, scalar curvature, Jacobi fields as well as isometric immersions.
Level: Undergraduate
Prerequisites: MATH 3300
Grading: Main Campus (UGrad, Grad)

MATH 4545 Harmonic Analysis 3 Credits

The first part of the course concentrates on some fundamental results in Fourier analysis (Bochner's theorem, Hardy-Littlewood maximal functions, Fefferman-Stein sharp functions, and the space of bounded mean oscillation) on Euclidean spaces. In the second part of this course, we are going to study singular integral operators through a few important example: Hilbert and Riesz transforms, the Szeg\{"}o projection operator on the Heisenberg group, and Cauchy integral on Lipschitz curves in the complex plane. Our goal is to explain some of the principal aspects of the great progress that has been made in the past thirty years or some toward understanding Calder\{'}on-Zygmund operators.

Level: Graduate, Undergraduate

Prerequisites: MATH 5031 or MATH 4531

Grading: Main Campus (UGrad, Grad)

MATH 4949 Tutorial: Mathematics 1-3 Credits

Tutorials on special topics are offered at the discretion of the instructor and with the permission of the Department Curriculum Committee.

Level: Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 5001 Applied Longitudinal Analysis 3 Credits

Studies and surveys where data are sampled in clusters or repeatedly sampled from subjects over time (e.g. panel studies) have become popular tools in many fields of research from the biomedical sciences to economics to public policy. The resulting data are typically correlated and potentially time dependent---issues that require a special set of modeling tools. This course covers the modern methods for the analysis of these types of data as well as the unbalanced and incomplete datasets common to such studies. Topics include an introduction to the analysis of correlated data, response profiles, parametric curves, covariance pattern models, random effects, and growth curve models. If time allows, the course will also explore generalized estimating equations (GEEs) and generalized linear mixed effects models (GLMMs). Applications will include real datasets from research in biology, biomedical science, economics, and political science. Analyses will be conducted using the statistical software, R.

Textbook: Applied Longitudinal Analysis, 2nd Edition Garrett M. Fitzmaurice, Nan M. Laird, James H. Ware ISBN: 978-0-470-38027-7

Restrictions: Must be enrolled in one of the following Levels: MN or MC Graduate Must be enrolled in one of the following Majors: Mathematics and Statistics

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

MATH 5005 Mathematics of Social Networks 3 Credits

Social network analysis (SNA) focuses on relationships between social entities. SNA is used widely in the social and behavioral sciences, as well as in political science, economics, logistics, industrial engineering and national security.

This course will present an introduction to the underlying mathematics used in SNA, in particular those drawn from graph theory and linear algebra. The primary focus of the applications of these methods is the analysis of relational data measured on groups of social agents or graph nodes. Topics to be discussed include an introduction to graph theory, link analysis, centrality measures, random graphs, and diffusions (such as spread of diseases) on networks.

Textbook: Networks: An Introduction Author: Mark Newman Publisher: Oxford University Press; 1 ISBN-10: 0199206651

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

Course registration restrictions:

Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5007 Mathematics of Climate 3 Credits

In this course, mathematics and statistics will used to answer current questions of interest in climate science and sustainability, and climate science will be used to motivate and explain techniques from applied mathematics and statistics.

The course will emphasize conceptual models that capture important aspects of the Earth's climate system: Energy balance and temperature distribution, ocean circulation patterns such as the Gulf Stream and El Niño – Southern Oscillation, ice caps and glaciation periods, the carbon cycle, and the biological pump. Mathematical and statistical topics will be selected from theories and methodologies for dynamical systems, bifurcation theory, ordinary and partial differential equations, signal processing, regression analysis, extreme value theory, and data assimilation.

Some knowledge of Matlab or R is needed.

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

Equivalent to MATH 4307

MATH 5010 Analysis II 3 Credits
This course is about analysis in several dimension. Topics include the Euclidean spaces, metric spaces, functions of several variables, differentiation and integration of functions of several variables, and the theorems of vector calculus. Most of the topics will be familiar from Multivariable Calculus (math-137). Many proofs will be presented and discussed. Students will be made familiar with some concepts of topology, the basic theory of metric spaces as well as the importance of compact sets in analysis. This course is expected to result in an appreciation for some of the central theorems of analysis such as the Inverse Function Theorem, Taylor's formula, the Change of Variable Formula in multiple integrals, and the Integral Theorems by Green, Gauss, and Stokes.
Level: Graduate, Undergraduate
Prerequisites: MATH 3310
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4310

MATH 5011 Intro Partial Diff Equations 3 Credits
Partial differential equations are essential tools in applied mathematics. This course synthesizes and builds upon techniques and concepts from multivariable calculus, linear algebra and ordinary differential equations to solve and analyze key linear and nonlinear partial differential equations. Topics include initial and boundary value problems, maximum principles, Fourier series, Green’s functions and conservation laws. Applications to physics, biology and other fields depending partly upon student interest will be central to the course.

Prerequisites: Math 137 (Multivariable Calculus) and Math 150 (Linear Algebra). Math 201 (Ordinary Differential Equations) is helpful but not required.
Level: Graduate, Undergraduate
Prerequisites: (MATH 137 or MATH 2370) and (MATH 150 or MATH 2250)
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4311

MATH 5014 Optimization 3 Credits
Optimization problems arise in a variety of fields, such as the most economic transport of goods from service points to destinations, the design of components in manufacturing, or the desire to minimize noises and vibrations in airplanes or cars. The mathematical formulation of optimization problems results in the task to minimize or maximize functions which may be subject to additional conditions or constraints. Optimization problems arise in a variety of fields, such as the most economic transport of goods from service points to destinations, the design of components in manufacturing, or the desire to minimize noises and vibrations in airplanes or cars. The mathematical formulation of optimization problems results in the task to minimize or maximize functions which may be subject to additional conditions or constraints.

Certain optimization problems, such as finding the extreme values (maxima and minima) of continuous functions of several variables, are already discussed in calculus. Of particular interest in this course are extreme value problems with constraints on the function, possibly given by additional equations, inequalities, or differential equations. According to the type and the nature of the constraint, different techniques of solving the optimization problem are to be developed. These include linear programming, nonlinear programming, variational problems, and optimal control. Students will see a good number of examples of optimization problems, study various analytical techniques of solving them, reinforce their knowledge of differential calculus of functions of several variables, and should gain an appreciation of two fundamental mathematical concepts: Linearity and Convexity.

This course can be taken for graduate credit.

Credits: 3

Prerequisites: Math-201 or equivalent. Certain optimization problems, such as finding the extreme values (maxima and minima) of continuous functions of several variables, are already discussed in calculus. Of particular interest in this course are extreme value problems with constraints on the function, possibly given by additional equations, inequalities, or differential equations. According to the type and the nature of the constraint, different techniques of solving the optimization problem are to be developed. These include linear programming, nonlinear programming, variational problems, and optimal control. Students will see a good number of examples of optimization problems, study various analytical techniques of solving them, reinforce their knowledge of differential calculus of functions of several variables, and should gain an appreciation of two fundamental mathematical concepts: Linearity and Convexity.

This course can be taken for graduate credit.

Credits: 3

Prerequisites: Math-201 or equivalent.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4314

MATH 5021 Riemannian Geometry 3 Credits
Riemannian Geometry is a second course in Differential Geometry. This course will cover differentiable manifolds, Riemannian metrics, affine and Riemannian connections, geodesics and their minimizing properties, sectional curvature, Ricci curvature, scalar curvature, Jacobi fields as well as isometric immersions.
Level: Graduate, Undergraduate
Prerequisites: MATH 3300
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5031 Real Analysis 3 Credits
Measure theory, Lebesgue integral, L^p spaces, duality, representation theorems, Radon- Nikodym and Fubini theorem, differentiation of integrals, a few facts from harmonic analysis.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4531

MATH 5032 Advanced Linear Algebra 3 Credits
Rigorous treatment of vector and inner product spaces, LU factorization, QR factorization, spectral theorem and singular value decomposition, Jordan form, positive definite matrices, quadratic forms, partitioned matrices, and norms and numerical issues, Hilbert spaces, compact operators, diagonalization of self-adjoint compact operators, Fredholm alternative.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4532, MATH 8110

MATH 5033 Numerical Analysis 3 Credits
Machine arithmetic, linear systems, root finding, interpolation and quadrature, eigenvalue problems, and ordinary differential equations.
Level: Graduate, Undergraduate
Prerequisites: MATH 310 or MATH 3310
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4533

MATH 5034 Complex Variables 3 Credits
Analytic functions, harmonic functions, Schwarz lemma, contour integration, conformal mapping, Riemann mapping theorem, Mittag-Leffler theorem, analytic continuation, theory of series of Weierstrass.
Level: Graduate, Undergraduate
Prerequisites: (MATH 310 or MATH 3310)
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 673

MATH 5035 Probability 3 Credits
A measure-theoretic introduction to probability. Topics will include definition of probability spaces and associated analytic tools, law of large numbers, central limit theorems, martingales, ergodic theorems, and diffusions. Time permitting, computational methods associated with probability will be introduced.
Level: Graduate, Undergraduate
Prerequisites: MATH 5031
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4535

MATH 5040 Functional Analysis 3 Credits
Hilbert spaces, Banach spaces, convergence in topological vector spaces, dual spaces, Riesz representation theorem, Theorem of Hahn-Banach, open mapping theorem, closed graph theorem, principle of uniform boundedness, spectral theorem for (un)bounded operators, semigroups of linear operators, Fredholm operators, and Fredholm index.
Level: Graduate, Undergraduate
Prerequisites: MATH 471 and (MATH 472 or MATH 5032)
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4540

MATH 5041 Partial Differential Equation 3 Credits
Linear and nonlinear first-order PDE, Sobolev spaces, distributions, Fourier transform, linear elliptic, parabolic, and hyperbolic equations, initial value problems, and boundary value problems.
Level: Graduate, Undergraduate
Prerequisites: MATH 471 and (MATH 480 (may be taken concurrently) or MATH 5040 (may be taken concurrently)) and (MATH 401 (may be taken concurrently) or MATH 5035 (may be taken concurrently))
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4541

MATH 5045 Harmonic Analysis 3 Credits
The first part of the course concentrates on some fundamental results in Fourier analysis (Bochner's theorem, Hardy-Littlewood maximal functions, Fefferman-Stein sharp functions, and the space of bounded mean oscillation) on Euclidean spaces. In the second part of this course, we are going to study singular integral operators through a few important example: Hilbert and Riesz transforms, the Szeg\{"}o projection operator on the Heisenberg group, and Cauchy integral on Lipschitz curves in the complex plane. Our goal is to explain some of the principal aspects of the great progress that has been made in the past thirty years or some toward understanding Calder\{'}on-Zygmund operators.
Level: Graduate, Undergraduate
Prerequisites: MATH 5031
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4545

MATH 5051 Probability Theory App 3 Credits
This is a MS level introduction to probability theory. Topics include probability measures, independence and conditional probability, discrete and continuous random variables and their properties, joint distributions, moment generating functions, notions of convergence, Laws of Large Numbers, and the Central Limit Theorem. A working knowledge of multiple integrals and partial derivatives is essential for this course. Some previous exposure to elementary probability and statistics, at least at the level of Math 1040, is recommended. This course is not based on measure theory.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5052 Deterministic Math Models 3 Credits
This is a MS level course in basic applied mathematical modeling with emphasis on derivation and analysis of models via linear algebra and differential equation methods. Topics in linear algebra include eigenvalues and eigenvectors, matrix decompositions such as singular value decomposition and their applications. Students develop modeling skills through example problems from various fields of applications which are interpreted into problems of differential equations. Some differential equations will be solved. Methods for analyzing/visualizing differential equations' solution behaviors will be provided, with emphasis on their significance on the applications.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5060 Survey Sampling 3 Credits
This is a MS level course that covers design and analysis of sample surveys. Sample designs include simple random sampling, systematic, stratified, cluster, double, and multistage sampling. Analytical methods include sample size determination, ratio and regression estimation, imputation for missing data, and nonsampling error adjustment.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 5061 Design of Experiments 3 Credits
This MS level course emphasizes applied and practical aspects of experimental design and analysis. Both design and analysis of experiments as well as software implementation (SAS and R) are discussed. The class mainly covers: Randomization, Analysis of Variance (ANOVA), Completely Randomized Designs, Multiple Comparisons and Contrasts, Power and Sample Size, Factorial Treatment Structure, Mixed Effects Models, Split-Plot Design (Cross-Over Design and Repeated Measures) and Analysis of Covariance (ANCOVA). Applications refer to clinical trials, dose-response modeling, bioequivalence assessment and quality control problems among others.
Level: Graduate, Undergraduate
Prerequisites: (MATH 510 or MATH 5200) and (MATH 503 or MATH 5151)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a program in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5070 Intro:Non-Parametric Stats 3 Credits
Prerequisite: MATH 5151. This MS level course provides a survey of nonparametric and rank based methods for data analysis. Frequently, common assumptions about the distributional form of data, required for many hypothesis testing or model building techniques, are violated. Ignoring these violations can lead to misleading or incorrect conclusions. Nonparametric and rank based methods provide statistically valid methods of analysis while requiring minimal assumptions about the data to be analyzed. Some topics covered will include one, two, and K-sample tests of hypotheses including, but not limited to, permutation tests, Wilcoxon Rank-Sum test, Mann-Whitney test, and the Kruskal Wallis test. Further topics including paired comparisons, blocked design, multivariate tests, and nonparametric bootstrap methods, among others, will also be covered. Students should expect a mix of theory and application.
Level: Graduate, Undergraduate
Prerequisites: (MATH 503 or MATH 5151)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

MATH 5151 Statistical Inference Model 3 Credits
Prerequisite: MATH 5051.

This is a MS level course.This course provides a rigorous introduction to the theory and applications of statistical inference. Topics to be covered include methods of estimation (optimization, EM algorithm, and MCMC), properties of point estimators, interval estimators, and likelihood-based tests (score, Wald, and LRT). The course will also explore application of these concepts in various statistical models.
Level: Graduate, Undergraduate
Prerequisites: (MATH 501 or MATH 5051)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5152 Numerical Methods for Data Sci 3 Credits
Prerequisites: MATH 5052 & MATH 5200; familiarity with programming and basic data science concepts would be beneficial but not mandatory.

Description: This MS level course provides a deep dive into the numerical techniques and algorithms that form the foundation of modern data science. Students will explore the mathematical principles and computational methods essential for solving large-scale, data-driven problems in science, engineering, and beyond. Key topics include (1) numerical linear algebra and matrix computations, critical for handling high-dimensional datasets; (2) optimization techniques for model training and tuning; (3) numerical solutions to differential equations in predictive modeling; (4) probabilistic and statistical numerical methods for uncertainty quantification; (5) applications in machine learning, big data analytics, and scientific computing. Hands-on programming exercises using Python or R will be integrated throughout the course, allowing students to implement and experiment with algorithms on real-world datasets. By the end of the course, participants will gain a robust understanding of numerical methods, enabling them to tackle complex problems in data science with precision and efficiency.
Level: Graduate, Undergraduate
Prerequisites: (MATH 502 or MATH 5052) and (MATH 510 or MATH 5200)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5200 Computing Using R Python 3 Credits
The goal of this MS level course is to provide students with a programming background sufficient for graduate level study in mathematics and statistics. The course gives an introduction to R and Python. R is widely used by practicing statisticians and data scientists. This portion of the course will be structured around statistical methods and examples will be worked out using both computing environments. Statistical topics to be covered include data management, simulation, descriptive statistics, graphical displays, hypothesis testing, correlation, regression models, and simple multivariate analysis methods. The introduction to Python will cover the basic structure of the language, commands, scripts and graphing.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5210 Cloud Computing 3 Credits
Prerequisite: MATH 5051 AND MATH 5200 or Equivalents Description: The topics covered in this MS level course are all concerned with analytics and computation involving data sets which may be very large, e.g. big data. The term analytics will refer to modeling and computation within specific mathematical frameworks such as large matrices and other definite file types, and tools that enable measuring, parsing, understanding and visualizing the data. The term big data refers to an analytical context that requires a distributed computing framework for effective processing. The course goals are to learn about advanced computational tools and methods utilized in the data science field. We will learn about how to use and administer cloud computing resources, useful utilities in the linux environment, and the AWS suite of cloud services. Among the AWS services we will focus on general use services (e.g. EC2, S3), but also the Hadoop distributed computing ecosystem (as implemented in AWS EMR), the map reduce framework, and the application of these concepts to working with and understanding large datasets. Prospective students should study the prerequisites listed below that include knowledge of the Linux command line language and some use of Python. This is a hands-on course.
Level: Graduate, Undergraduate
Prerequisites: (MATH 510 or MATH 5200)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a program in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment limited to students in the MS-MAST program.

Enrollment is limited to Graduate level students.

MATH 5310 Deep Learning 3 Credits
Prerequisites: MATH 5051 AND MATH 5200 or Equivalents.

Description: This MS level course is an introduction to Neural Networks and Deep Learning. This is a first course on the mathematical foundations of neural networks with practical applications in R or Python. This course will begin with review of preliminaries in linear algebra, machine learning, and numerical computation. Then this course will move on to several neural network architectures such as feed forward networks, recurrent neural networks (RNN), convolutional neural networks (CNN), long short-term memory (LSTM) networks, autoencoders, generative adversarial networks (GAN), and transformers. Students will learn the mathematics of these architectures, their real-world applications, optimization techniques, and implementations in R or Python, depending on the student's choice.
Level: Graduate, Undergraduate
Prerequisites: (MATH 501 or MATH 5051) and (MATH 510 or MATH 5200)
Grading: Main Campus (UGrad, Grad)

MATH 5320 Supervised Stat Learning 3 Credits
MATH 5320 Supervised Statistical Learning is a MS level course. Machine or statistical learning is concerned with algorithms that automatically improve their performance through experience and active feedback. This course covers topics such as neural networks, probabilistic networks, statistical learning methods (logistic regression, decision trees, random forests, among others), and reinforcement learning. This course is designed to provide a solid mathematical and statistical background in the theory and applications of supervised modeling and algorithms.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5330 Data Mining 3 Credits
This course presents an introduction to computational and statistical methods for exploring large data sets and discovering patterns in them. Visualization and other exploratory methods will be used throughout the course. The course surveys methods in predictive modeling (classification) including decision trees, Naïve Bayes and nearest neighbor methods. In the process, we will study discretization, data normalization and attribute selection as well as sampling methods like cross-validation, bagging and boosting. Other topics will include cluster analysis, association analysis, anomaly detection and text mining. For all topics studied, students will work with various real and constructed data sets to see the impact of different distributions on the performance of the algorithms. A variety of performance metrics will be studied. The software Weka, R and Excel will be used in the course, although only basic knowledge of R and Excel will be assumed. Fall semester. Text: Intro to Data Mining Author: Tan ISBN: 9780321321367 Copyright Year: 2006 Publisher: Addison Wesley Restrictions: Must be enrolled in one of the following Levels: MN or MC Graduate Must be enrolled in one of the following Majors: Mathematics and Statistics
Level: Graduate, Undergraduate
Prerequisites: (MATH 503 or MATH 5151)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5340 Social Network Analysis 3 Credits
This MS level course will cover the mathematical concepts used in Social Network Analysis (SNA), in particular those drawn from graph theory and linear algebra. The primary focus of the applications of these methods is the analysis of relational data measured on groups of social agents or graph nodes. Topics to be discussed include graph theory, link analysis, centrality measures, estimation, sampling, large-scale analysis, functional granulation, visualization of network data including issues of validity and representation, and diffusions on networks. After identifying an area of interest, students will prepare a Research Paper and Final Project that uses tools from network theory to quantify the structure of their system and provide a meaningful interpretation of their findings.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)

MATH 5410 Operations Research 3 Credits

This is a MS level course covering the foundations of operations research with emphasis on mathematical modeling, linear optimization, and metaheuristics. Linear optimization (or linear programming, LP) is a fundamental branch of optimization, with applications to several areas such as physical sciences, health care, manufacturing, logistics, computer science, and finance. This course will provide an integrated view of the theory, solution techniques and applications of LP. Metaheuristics are algorithms that can be used to find quality solutions to a variety of optimization problems, where analytic solutions are impractical. There are many classic examples of optimization via LP. The diet problem takes a set of foods that have varying nutrient levels and costs. The constraint would be in the form of a recommended daily minimum nutritional intake, and the problem is to satisfy the nutritional goals at minimum cost. A background in basic Python, linear algebra, and multivariate calculus is assumed. Topics covered include mathematical modeling, LP formulation, the simplex method, sensitivity analysis, network flows, simulated annealing, and genetic algorithms. Mathematical modeling software will be used throughout the course for solving examples.

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

Course registration restrictions:

Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5420 Financial Mathematics 3 Credits

This is a MS level course on the mathematics of financial derivatives. It covers the modeling of underlying assets as Browning motions and the pricing of derivatives by the Black-Scholes analysis. Topics covered include present value, risk free rates, drift terms, asset price volatility, stochastic differential equations and applications both within finance and elsewhere, Merton Firm Value, partial differential equations (PDE) and risk analysis including value at risk. Both the PDE and binomial Black-Scholes pricing models are covered.

Level: Graduate, Undergraduate

Prerequisites: MATH 5051 and MATH 5052

Grading: Main Campus (UGrad, Grad)

Course registration restrictions:

Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5500 Regression Models 3 Credits

This MS level course will focus on the theory and application of regression methods for statistical modeling and data analysis. Emphasis will be in the following areas: simple and multiple regression, inference and prediction, model building and diagnostics, model selection and validation, penalized regression (ridge, LASSO, elastic net), and selected topics in non-Gaussian and non-linear models. Practical issues involved in implementation of these methods will be presented using statistical software R based on example problems from a wide range of applications.

Level: Graduate, Undergraduate

Grading: Main Campus (UGrad, Grad)

Course registration restrictions:

Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5510 Generalized Lin Models 3 Credits

This is a MS level course. Generalized Linear Models (GLM) provide a unifying statistical framework for analyzing data with a response variable in the exponential family distribution. This course will focus on the theory and application of GLMs. It will cover commonly encountered GLMs, including a review of linear models for normally distributed responses, models for binary outcomes (logistic regression and probit models), models for multinomial outcomes (polytomous regression), models for ordinal responses (proportional odds model), models for count data (Poisson regression, negative binomial regression, zero-inflated models). The statistical software packages SAS and R will be used to illustrate the implementation of these models to data from a wide range of applications.

Level: Graduate, Undergraduate

Prerequisites: (MATH 503 or MATH 5151) and (MATH 651 or MATH 5500)

Grading: Main Campus (UGrad, Grad)

Course registration restrictions:

Enrollment is limited to students with a program in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5520 Time Series 3 Credits
Prerequisite: MATH-5151 Mathematical Statistics or equivalent; MATH-5200 is optional but highly encouraged (Note: basic familiarity with R is expected). Description: This MS level course will focus on the theory and application of methods for time series data. This course discusses the modeling and forecasting of univariate time series. Emphasis will be in the following areas: Course topics include exploratory methods, white noise and random walk models, smoothing techniques, regression methods for time series data, time series models for stationary and non-stationary data including autoregressive (AR), moving average (MA) and autoregressive moving average(ARMA) models as well as advanced models (ARCH, GARCH, etc.), and advanced topics in machine learning for time series and multivariate time series (vector autoregressive models). Applications to real-world data sets will be explored using the software package R. Examples are drawn from a variety of areas including finance, business, economics, public policy, health, environment and ecology.
Level: Graduate, Undergraduate
Prerequisites: (MATH 503 or MATH 5151)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a program in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5530 Applied Multivariate Analysis 3 Credits
This course is an introduction to the analysis of multivariate data. Topics include matrix algebra and random vectors, the multivariate normal distribution, Hotelling's T^2, multivariate linear regression models, principal components, factor analysis, and discriminant analysis. The overarching learning goal for this course is for students to acquire an understanding and ability to analyze multivariate data using the software R. Students will (both in and outside of class) complete analytical and computational assignments, culminating in the completion of an applied multivariate analysis project and presentation.
Level: Graduate, Undergraduate
Prerequisites: (MATH 501 or MATH 5051)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment limited to students in the MS-MAST program.

Graduate level students may **not** enroll.

MATH 5600 Bayesian Statistics 3 Credits
Prerequisite: MATH 5051

Description: This MS-level course provides a practical introduction to Bayesian statistical methods. It assumes familiarity with concepts in probability theory and statistical inference, as well as some programming experience. Students will learn the fundamentals of Bayesian inference and will be exposed to Monte Carlo simulation methods. The first part of the course will focus on the specification of prior distributions, the evaluation of posterior and predictive distributions, and the theory of Bayesian estimation and hypothesis testing. The second part of the course will focus on Monte Carlo simulation with an emphasis on Markov chain Monte Carlo methods, including the Gibbs sampler and the Metropolis-Hastings algorithm. A variety of statistical models will be considered and illustrated with examples from a wide range of applications. The open source software R will be used to carry out Bayesian analysis.
Level: Graduate, Undergraduate
Prerequisites: MATH 5051
Grading: Main Campus (UGrad, Grad)

MATH 5700 Num Optim for AI Data Sci 3 Credits
Optimization is central to any problem involving decision making, whether in engineering or economics. The task of decision making entails choosing between various alternatives. This choice is governed by our desire to make the ”best” decision. The measure of goodness of the alternatives is described by an objective function or performance index. Optimization theory and methods deal with selecting the best alternative in the sense of the given objective function. The area of optimization has received enormous attention in recent years, primarily because of the rapid progress in computer technology. The main objective of this course is to provide working knowledge on various types of optimization problems including linear and nonlinear program, constrained/unconstrained, smooth/nonsmooth optimization problems. Some of the most recent approaches such as alternating minimization, operator splitting, penalty methods will be discussed. Practical applications in image/signal processing, medical imaging, and data analysis may be discussed. Suggested textbook: Numerical Optimization, Jorge Nocedal and Stephen J. Wright, Second Edition, 2006 (textbook is not required). Prerequisite: MATH 504.
Level: Graduate, Undergraduate
Prerequisites: (MATH 504 or MATH 5152)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a program in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5710 Unsupervised Learning 3 Credits
Prerequisite: MATH 5051 and MATH 5151 and MATH 5200

Description: This MS level course covers a range of methods in unsupervised learning with a focus on latent feature inference and learning as well as generative models. We will start with classical methods such as PCA, then consider learning and inference for different statistical models, with an emphasis on connections to clustering and several examples of Bayes nets. In this context we'll cover MCMC and variational approaches. Roughly the last third of the course will cover deep learning methods for unsupervised learning including autoencoders, variational autoencoders and, time permitting, generative diffusions and transformers. Coding in Python and R will be a central component of the course.
Level: Graduate, Undergraduate
Prerequisites: (MATH 501 or MATH 5051) and (MATH 503 or MATH 5151) and (MATH 510 or MATH 5200)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to students with a major in Mathematics and Statistics, Mathematics and Statistics, Mathematics and Statistics or Mathematics and Statistics.

Enrollment is limited to Graduate level students.

MATH 5925 Internship 0-1 Credits
Students who are simultaneously engaging in an internship in a private, non-profit, or governmental organization may enroll in MATH -5925 to gain credit. International students who would like to obtain CPT approval must enroll in MATH-5925. Qualifying internship opportunities must involve substantial application of the mathematical, statistical and computational skills acquired in the program courses for solving real world problems. All students in the Mathematics/ Statistics (MAST) graduate program who are eligible to engage in an internship must receive Program Director approval to enroll in this course. International students must complete a full academic year in the program (Fall and Spring semesters) to be able to apply for CPT. Students must submit a proposal of the topics that they will be working on during the internship and a final oral and/or written presentation is required.
Level: Graduate, Undergraduate
Grading: Pass/Fail Default
Course registration restrictions:
Enrollment limited to students in the MS-MAST program.

Enrollment is limited to Graduate level students.

MATH 7949 Tutorial: Mathematics 1-4 Credits
Tutorial in Mathematics of Econometrics
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8100 Real Analysis 3 Credits
This is a PhD-level course in real analysis covering measure, integration, and applications. Topics include: measure theory, the Lebesgue integral, L^p spaces, duality, representation theorems, the Radon-Nikodym and Fubini theorems, and if time allows differentiation of integrals, and a few facts from harmonic analysis. This class provides preparation for the real analysis portion of the Comprehensive Exam.
Level: Graduate
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 471
Course registration restrictions:
Enrollment limited to students in the PHD-APMA program.

Enrollment is limited to Graduate level students.

MATH 8110 Advanced Linear Algebra 3 Credits
This is a PhD-level course that covers the rigorous treatment of vector and inner product spaces, LU factorization, QR factorization, spectral theorem and singular value decomposition, Jordan form, positive definite matrices, quadratic forms, partitioned matrices, and norms and numerical issues. Further topics may include the Cayley-Hamilton Theorem, the Cauchy-Binet Formula, the Dunford decomposition, and the Theorem by Toeplitz-Hausdorff. This class provides preparation for the linear algebra portion of the Comprehensive Exam.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 4532
Course registration restrictions:
Enrollment limited to students in the PHD-APMA program.

Enrollment is limited to Graduate level students.

MATH 8120 Numerical Analysis 3 Credits
This course is at the level of PhD students before the qualifying exams. The topics covered are solving equations via iterations, polynomial interpolation, splines interpolation, numerical differentiation and integration, solving initial and boundary value problems of ordinary differential equations, and solving linear systems of equations. The goal is to gain skills for constructing, analyzing, evaluating and improving numerical algorithms in the context of the topics listed above.
Level: Graduate, Undergraduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment limited to students in the PHD-APMA program.

Enrollment is limited to Graduate level students.

MATH 8130 Complex Analysis 3 Credits

This is a PhD-level course that rigorously covers core topics in classical complex analysis. These topics include: analytic functions; harmonic functions; the Schwarz lemma; contour integration; conformal mapping; the Riemann mapping theorem; the Mittag-Leffler theorem; analytic continuation. This class provides preparation for the complex analysis portion of the Comprehensive Exam.
Level: Graduate, Undergraduate
Prerequisites: MATH 8100
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8150 Probability 3 Credits

This is a PhD-level course that is a measure-theoretic introduction to probability. Topics will include definition of probability spaces and associated analytic tools, law of large numbers, central limit theorems, martingales, ergodic theorems, and diffusions. Time permitting, computational methods associated with probability will be introduced.
Level: Graduate
Prerequisites: MATH 8100
Grading: Main Campus (UGrad, Grad)

MATH 8180 Computational Mathematics 3 Credits

This is a PhD-level course. This course will survey key elements of computational mathematics with a particular emphasis on methods applicable to data. Course topics will include optimization, matrix analysis and approximation, graphs and networks, and linear and non-linear methods in dimension reduction and function approximation. An emphasis will be placed on computation in high dimensions and associated theory. Students who lack a working knowledge of a scripting language such as R or Python are welcome, but should talk to the instructor prior to taking the course.
Level: Graduate
Prerequisites: MATH 8110 and MATH 8120
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 818
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8200 Functional Analysis 3 Credits

Hilbert spaces, Banach spaces, convergence in topological vector spaces, dual spaces, Riesz representation theorem, Theorem of Hahn-Banach, open mapping theorem, closed graph theorem, principle of uniform boundedness, spectral theorem for (un)bounded operators, semigroups of linear operators, Fredholm operators and Fredholm index.
Level: Graduate
Prerequisites: (MATH 671 or MATH 8100)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8250 Partial Differential Equation 3 Credits

Linear and nonlinear first-order PDE, Sobolev spaces, distributions, Fourier transform, linear elliptic, parabolic and hyperbolic equations, initial value problems and boundary value problems.
Level: Graduate
Prerequisites: (MATH 671 or MATH 8100)
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment limited to students in the PHD-APMA program.

Enrollment is limited to Graduate level students.

MATH 8260 Harmonic Analysis 3 Credits

The first part of the course concentrates on some fundamental results in Fourier analysis (Bochner's theorem, Hardy-Littlewood maximal functions, Fefferman-Stein sharp functions, and the space of bounded mean oscillation) on Euclidean spaces. In the second part of this course, we are going to study singular integral operators through a few important example: Hilbert and Riesz transforms, the Szeg\{"}o projection operator on the Heisenberg group, and Cauchy integral on Lipschitz curves in the complex plane. Our goal is to explain some of the principal aspects of the great progress that has been made in the past thirty years or some toward understanding Calder\{'}on-Zygmund operators
Level: Graduate
Prerequisites: MATH 8100
Grading: Main Campus (UGrad, Grad)
Equivalent to MATH 826
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8270 Riemannian Geometry 3 Credits

This is a PhD-level course. Riemannian Geometry is a second course in Differential Geometry. This course will cover differentiable manifolds, Riemannian metrics, affine and Riemannian connections, geodesics and their minimizing properties, sectional curvature, Ricci curvature, scalar curvature, Jacobi fields as well as isometric immersions.
Level: Graduate
Prerequisites: MATH 8110
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 8300 Selected Topics in PDE 3 Credits
This is a PhD level course.

This course is a continuation of MATH 8250. Topics include Nonlinear first-order PDE, the method of characteristics, Hamilton-Jacobi equations, conservation laws, Fourier transform, Laplace transform, and the Radon transform. In the context of similarity solutions plane waves, traveling waves, solitons, group velocity, and phase velocity will be introduced. The method of stationary phase will be discussed in the context of asymptotic solutions. Solutions based on power series and the Cauchy-Kovalevskaya Theorem are studied. The course concludes with the study of semigroups of linear operators. The method of semigroup will be applied to various linear and some non-linear equations and produce strong existence, uniqueness, and stability results.
Level: Graduate
Prerequisites: MATH 8250
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 9990 APMA Doctoral Seminar
APMA Doctoral Seminar\ Graduation requirement for the first 2 years of the APMA Program
Level: Graduate
Grading: Pass/Fail Default
Course registration restrictions:
Enrollment limited to students in the PHD-APMA program.

MATH 9991 Continuous Registration
Level: Graduate
Grading: No Grade
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 9992 Continuous Registration
Level: Graduate
Grading: No Grade
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 9993 Continuous Registration
Level: Graduate
Grading: No Grade
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 9994 Continuous Registration
Level: Graduate
Grading: Main Campus (UGrad, Grad)
Course registration restrictions:
Enrollment is limited to Graduate level students.

MATH 9999 Thesis Research
Conduct research towards completion of the PhD degree under the guidance of a faculty member. Section 01: for students who are taking or have taken 27-cr or less of courses; Section 03: for students taking courses beyond the 27-cr required; Section 05: for students who are paid as teaching assistants.
Level: Graduate
Grading: No Grade
Course registration restrictions:
Enrollment is limited to Graduate level students.