MATHEMATICAL AND STATISTICAL SCIENCES

Chair: Julien Langou
Associate Chair: Troy Butler
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Overview

The Department of Mathematical and Statistical Sciences at the University of Colorado Denver offers degrees and certificates at the undergraduate and graduate levels in mathematics, applied mathematics, data science, and statistics through coursework, research and industrial collaboration. Traditional courses such as calculus, linear algebra, probability, statistics and discrete mathematics are offered regularly by the department. In addition, contemporary subjects such as high-performance computing; numerical analysis, optimization, statistical methods, and operations research are also well represented by course offerings and faculty interests. In all of its activities, the department embodies the outlook that mathematics, statistics, computing and data science are powerful tool that can be used to solve problems of immediate and practical importance.

Apart from the specialized mathematical and statistical skills acquired through course work, the degrees and certificates also provide general skills that are valued by many employers. These skills include problem solving, critical thinking, analysis, facility with data, the ability to process quantitative information, and perhaps most important of all, the ability to learn new skills and concepts quickly

Center for Computational & Mathematical Biology

Director: Weldon Lodwick
Telephone: 303-315-1733
Website: http://ccmb.ucdenver.edu/

The Center for Computational Biology (CCMB) is a multidisciplinary center focused on computational and mathematical biology research and education.

Center for Computational Mathematics

Director: Jan Mandel
Telephone: 303-315-1703
Website: http://ccm.ucdenver.edu

The Center for Computational Mathematics is composed of faculty members who have an interest in computational mathematics, the study of solving mathematical problems with computers. The center resides in the Department of Mathematical and Statistical Sciences and includes faculty members from various other departments. The primary goal of the center is to foster research in computational mathematics and to maintain a strong educational program at all levels. It has extensive ties with industry along the Front Range and with government laboratories throughout the nation. It offers students an excellent opportunity to receive training and experience in this exciting new field. The center operates several supercomputing clusters.

Math Clinic

Website: https://clas.ucdenver.edu/mathematical-and-statistical-sciences/math-clinic (https://clas.ucdenver.edu/mathematical-and-statistical-sciences/math-clinic/)

Each semester, the Department of Mathematical and Statistical Sciences conducts math clinics that are open to both undergraduate and graduate students. Each clinic is sponsored by a business, government agency or research organization. The clinic sponsor provides a specific project on which students work with the supervision of a faculty member and a sponsor representative. Every clinic results in a final report to the sponsor and provides participating students with an opportunity to apply mathematics to relevant problems. Recent math clinic sponsors include Raytheon, Lockheed Martin, Xenometrix, Budget Truck Rental and United Launch Alliance.

Statistical Consulting Service

The Department of Mathematical and Statistical Sciences regularly offers a graduate course in statistical consulting in which students work on problems provided by researchers and clients at CU Denver and in the Denver metropolitan area. Potential clients should contact the department at 303-315-1700.

Graduate Program

Director: Steffen Borgwardt
Telephone: 303-315-1700

The Department of Mathematical and Statistical Sciences offers the MS degrees in Applied Mathematics and Statistics and the PhD degree in Applied Mathematics. Each of these degree programs conforms to the rules and policies of the Graduate School Policies and Procedures (http://catalog.ucdenver.edu/cu-denver/graduate/graduate-school-policies-procedures/).

Detailed descriptions of the requirements for the MS and PhD degrees are maintained at www.math.ucdenver.edu (http://www.math.ucdenver.edu). The following is an abbreviated summary of these requirements.

Financial Support

PhD students are encouraged to apply for teaching assistantships. A variety of other opportunities for financial support are also available.

Applied Statistics Certificate

Director: Joshua French
Telephone: 303-315-1709
Website: https://clas.ucdenver.edu/mathematical-and-statistical-sciences/graduate-certificate-applied-statistics (https://clas.ucdenver.edu/mathematical-and-statistical-sciences/graduate-certificate-applied-statistics/)
Click here (http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-liberal-arts-sciences/mathematical-statistical-sciences/applied-statistics-graduate-certificate/) to learn about the **requirements for the Graduate Certificate in Applied Statistics**.

Requirements for Admission

To begin graduate work toward the MS or PhD degrees in Applied Mathematics, a student should have at least the following preparation:

30 semester hours of mathematics with each course grade at B- or better and an overall GPA of 3.0 or better, at least 24 of which are upper-division courses. These courses should include one semester of advanced calculus or introduction to analysis, one semester of linear algebra and one semester of either differential equations, abstract algebra, discrete mathematics or probability.

To begin graduate work toward the MS in Statistics, a student should have at least the following preparation: a baccalaureate (not necessarily in mathematics or statistics) from an accredited college or university with a grade point average (GPA) of 3.0 or above. Students must have taken three semesters of calculus (through multivariate calculus), linear algebra, and a calculus-based statistics course that covers basic probability and statistical distributions. Admitted students are generally expected to have completed several additional upper-division mathematics courses on top of the minimum requirements, though students from non-mathematics backgrounds who meet minimum requirements and have exceptional track records will be considered on a case-by-case basis.

Students who do not have all the prerequisites may be admitted with prerequisite deficiencies with the understanding that those deficiencies must be removed after admission. Students who have a cumulative undergraduate GPA that is less than 3.0 may be eligible for provisional admission to the master's program (see also the Graduate School (http://catalog.ucdenver.edu/cu-denver/graduate/information-graduate-students/admissions-requirements/) admission requirements).

Application Deadlines

Applications to the MS or PhD programs should be submitted by the following target dates to be guaranteed full consideration. International students should submit their applications at least one month prior to these target dates.

Target Dates for PhD Program	Target Dates for MS Program
January 15: fall semester	**July 15:** fall semester
No summer admissions for the PhD program	**March 1:** summer semester
No spring admissions for the PhD program	**Nov 1:** spring semester

Applications received after the target dates may still be considered for admission, depending on space availability.

Applied Statistics Graduate Certificate

The minimum admission requirements for students applying for the Graduate Certificate in Applied Statistics are:

- A bachelor's degree (not necessarily in mathematics or statistics) from an accredited college or university
- A grade point average (GPA) of 3.0 or above during their bachelor's degree.
- Students must have taken three semesters of calculus (through multivariate calculus), linear algebra, and a calculus-based statistics course that covers basic probability and statistical distributions.

Subject to approval by the Director of the Statistical Programs and the Graduate Committee, students with prerequisite deficiencies may be admitted with the understanding that those deficiencies must be removed after admission. Courses taken to fulfill admission deficiencies may not be counted toward the certificate.

Programs

- Applied Mathematics, MS (http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-liberal-arts-sciences/mathematical-statistical-sciences/applied-mathematics-ms/)
- Applied Mathematics, PhD (http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-liberal-arts-sciences/mathematical-statistical-sciences/applied-mathematics-phd/)
- Statistics, MS (http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-liberal-arts-sciences/mathematical-statistical-sciences/statistics-ms/)
- Applied Statistics Graduate Certificate (http://catalog.ucdenver.edu/cu-denver/graduate/schools-colleges-departments/college-liberal-arts-sciences/mathematical-statistical-sciences/applied-statistics-graduate-certificate/)

Faculty

Professors:

Stephen Hartke, PhD, Rutgers University
Michael S. Jacobson, PhD, Emory University
Julien Langou, PhD, INSA, Toulouse, France
Weldon A. Lodwick, PhD, Oregon State University
Jan Mandel, PhD, (equivalent), Charles University, Czechoslovakia
Florian Pfender, PhD, Emory University
Stephanie A. Santorico, PhD, North Carolina State University

Associate Professors:

Stephen Billups, PhD, University of Wisconsin-Madison
Steffen Borgwardt, PhD, Technische Universität München
Troy Butler, PhD, Colorado State University
Joshua French, PhD, Colorado State University
Audrey Hendricks, PhD, Boston University
Burton Simon, PhD, University of Michigan, Ann Arbor
Diana White, PhD, University of Nebraska

Assistant Professors:

Erin Austin, PhD, University of Minnesota
Yaning Liu, PhD, Florida State University
Emily Speakman, PhD, University of Michigan

Associate Professors, Clinical Teaching Track:

RaKissa Manzanares, PhD, University of Northern Colorado
Adam Spiegler, PhD, University of Arizona

Senior Instructors:

Robert Rostermundt, PhD, University of Colorado Denver

Instructors:

Joe Bilello, MS, Long Island University
Lance Lana, MS, University of Colorado Denver
Dmitriy Ostrovskiy, PhD, State University of New York at Stony Brook

International College of Beijing Faculty:

Joseph Quarcoo, PhD, University of South Florida

Research Faculty:

Aime Fournier, PhD, Yale University

Emeritus Faculty:

William Briggs, PhD, Harvard University
William E. Cherowitzo, PhD, Columbia University
Kathryn L. Fraughnaugh, PhD, University of Houston
Andrew Knyazev, PhD, Russian Academy of Sciences
J. Richard Lundgren, PhD, Ohio State University
Stanley E. Payne, PhD, Florida State University

Mathematics (MATH) Courses

MATH 5010 - History of Mathematics (3 Credits)
A history of the development of mathematical techniques and ideas from early civilization to the present, including the inter-relationships of mathematics and sciences. Note: this course assumes that students have mathematical knowledge equivalent to MATH 1401. Prereq: Graduate standing. Not open to students who have had MATH 4010. No credit for applied math graduate students. Cross-listed with MATH 4010. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors
Typically Offered: Spring.

MATH 5012 - An Advanced Perspective on Number and Operation (2 Credits)
Advanced study of number and operation, including why the various procedures from arithmetic work and connections to algebraic reasoning. Focuses on using rigorous mathematical reasoning and multiple representations to explain concepts. Note: Does not count toward graduate degrees in applied mathematics. Note: this course assumes that students have taken MATH 3000 or an equivalent course. Prereq: Graduate standing. Cross-listed with MATH 4012. Max hours: 2 Credits.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors

MATH 5013 - An Inquiry-based Approach to Geometry (1 Credit)
An inquiry-based approach to middle-level and Euclidean geometry. Topics include: polygons and the angle relationships, constructions, Pythagorean theorem and perimeter, area and volume, similarity and congruence, circles. Note: Does not count toward a graduate degree in applied mathematics. Note: this course assumes that students have taken MATH 3000 or an equivalent course. Prereq: Graduate standing. Cross-listed with MATH 4013. Max hours: 1 Credit.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors

MATH 5014 - Statistical Knowledge for Teaching (1 Credit)
A problem-based statistics seminar aimed at secondary teachers. Topics include: the central limit theorem, the law of large numbers, probability, measures of central tendency and variability, sampling distributions, regression, and hypothesis testing. Note: Does not count toward a graduate degree in applied mathematics. Note: this course assumes that students have taken MATH 3800 or an equivalent course. Prereq: Graduate standing. Cross-listed with MATH 4014. Max hours: 1 Credits.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors

MATH 5015 - Capstone Course for Secondary Teachers (3 Credits)
High school mathematics from an advanced perspective: analyses of alternative definitions, extensions and generalizations of familiar theorems; discussions of historical contexts in which concepts arose; applications of mathematics. Note: Does not count toward a graduate degree in applied mathematics. Note: this course assumes that students have taken MATH 3210, 4310 and 3140 or equivalent. Prereq: Graduate standing. Cross-listed with MATH 4015. Max hours: 3 Credits.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors

MATH 5016 - RM-MSMSP Research Experience for Teachers - Math Cohort (1-6 Credits)
The Research Experience for Teachers (RET) program is a five-week research exploration in which twelve RM-MSMSP teachers will raise their level of relevant mathematics understanding by engaging in a "hands on" workshop, transforming what they have learned into new curricular materials that will improve the mathematics abilities of their students and hopefully stimulate them to consider a STEM career. Note: Credit may not apply toward any CLAS degree. Department consent required. Max hours: 6 Credits.
Grading Basis: Letter Grade

MATH 5017 - Topics in Mathematics for Teachers (0.3-50 Credits)
Topics vary from semester to semester. Designed for professional mathematics teachers. Note: This course will not count toward a degree in applied mathematics. Prereq: permission of instructor. Repeatable. Max Hours: 50 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 50.

MATH 5027 - Topics in Applied Mathematics (3 Credits)
Selected topics in mathematical problems arising from various applied fields such as mechanics, electromagnetic theory, economics and biological sciences. Prereq: Graduate stadning in Applied Mathematics, Statistics, or Dual MATH MA/ECON MA, or permission of the instructor. Max hours: 3 Credits.
Grading Basis: Letter Grade
Restriction: Graduate standing in Applied Mathematics, Statistics, or Dual MATH MA/ECON MA.

MATH 5070 - Applied Analysis (3 Credits)
Metric spaces, uniform convergence, elements of Banach spaces, elements of functions of complex variable. Problem solving and independent proof writing. Review of selected advanced topics in analysis for the PhD preliminary examination. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of two semesters of undergraduate real analysis (e.g., MATH 4310 and MATH 4320). Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 5110 - Theory of Numbers (3 Credits)
Every other year. Topics include divisibility, prime numbers, congruences, number theoretic functions, quadratic reciprocity, and special diophantine equations, with applications in engineering. Prereq: Graduate Standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in mathematical proof (e.g. MATH 3000). Cross-listed with MATH 4110. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 5135 - Functions of a Complex Variable (3 Credits)
Infrequent. The complex plane, infinite series and products, elementary special functions, Cauchy-Riemann equations, conformal mapping, complex integration, Cauchy integral theory, and residue theory. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have mathematical knowledge equivalent to two semesters of undergraduate-level real analysis (e.g. MATH 4310, MATH 4320) or to a semester of graduate-level real analysis (e.g., MATH 5070). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5198 - Mathematics for Bioscientists (3 Credits)
Infrequent. Develops mathematical reasoning: introduces linear algebra, discrete structures, graph theory, probability, and differential equations, using applications to molecular biology. Note: No credit for mathematics or engineering students. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have mathematical knowledge equivalent to two semesters of calculus (e.g., MATH 1401, MATH 2411). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5310 - Probability (3 Credits)
The course covers axioms of probability, combinatorial probability, conditional probability, random variables (discrete, continuous, and multivariate), expected value (mean, moments, variance, covariance, etc.), limit theorems (laws of large numbers, Central Limit Theorem), Poisson processes and Markov chains. Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of differential and integral calculus (e.g., MATH 2411). Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Fall.

MATH 5320 - Statistical Inference (3 Credits)
Methods for constructing sampling distributions; sufficient, minimal sufficient, ancillary and complete statistics; methods for constructing and evaluating point estimators; estimator optimality; methods for constructing and evaluating hypothesis tests; methods for constructing and evaluating confidence interval estimators; asymptotic properties of estimators. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Spring.

MATH 5337 - Intro to Statistical and Machine Learning (3 Credits)
This is an applied, hands-on course in statistical and machine learning. This course will introduce students to the general framework, best practices, model training, and assessment for machine learning methods from the viewpoint of statistics. Both supervised and unsupervised methods are covered including penalized regression, knearest neighbors, clustering, and neural networks. Additional machine learning topics such as random forests and support vector machines are included as time permits. Ultimately, students will learn how and why to use a particular method, how to validate and explain the results, and apply the methods to real data. Note: It is recommended that students are comfortable learning a statistical computing language such as R or Python as these will be taught alongside the course material. Students with minimal programming experience should expect to spend more time learning the programming language throughout the course. Prereq: MATH 4387 or MATH 5387 or MATH 4830 or MATH 5830 or BIOL 3763 with a C- or higher. Students who have completed a different statistics course that contains regression and computing may seek instructor permission to enroll. Cross-listed with MATH 4337. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: MATH 4387 or MATH 5387or MATH 4830 or MATH 5830 or BIOL 3763 with a C- or higher.

MATH 5350 - Mathematical Theory of Interest (3 Credits)
Rates of interest, term structure of interest rates, force of interest, yield rate, principal, equation of value, annuity, perpetuity, stocks, bonds, other financial instruments. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in probability (e.g., MATH 4810). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5351 - Actuarial Models (3 Credits)
Severity models, frequency models, aggregate models, risk measures, ruin theory, construction and selection of empirical models, credibility, simulation. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note:This course assumes that students have the equivalent of undergraduate-level courses in probability and statistics (e.g. MATH 4810, MATH 4820, MATH 3382). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5387 - Applied Regression Analysis (3 Credits)
Topics include simple and multiple linear regression, model diagnostics and remediation, and model selection. Emphasis is on practical aspects and applications of linear models to the analysis of data in business, engineering and behavioral, biological and physical sciences. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of an undergraduate-level course in statistics (e.g., MATH 4820). No co-credit with MATH 4830/5830. Cross-listed with MATH 4387. Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Fall.

MATH 5388 - Machine Learning Methods (3 Credits)
Regression, neural networks, clustering, support vector machines, random forests, and other prediction/classification techniques will be used to solve supervised and unsupervised learning problems. This course will connect each topic with the underlying mathematical foundation such as optimization methods and statistical inference. A key focus is deriving the methods and their properties to guide proper application. Students will learn how to apply methods using standard libraries from Python, R, or Matlab. Prereq: Graduate standing in Applied Mathematics or Statistics or in one of the 4+1 BS-MS programs. Cross-listed with MATH 4388. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics or in one of the 4+1 BS-MS programs. (AMEN-MS, AMEN-PHD, STAT-MS, MATH BS-BMA).

MATH 5390 - Game Theory (3 Credits)
Zero-sum and non-zero-sum games; Nash equilibrium and the principle of indifference; Shapley value and other concepts of fair division; Evolutionary game theory, ESS, and evolutionary population dynamics. Applications in economics, business, and biology. Note: this course assumes that students have the equivalent of MATH 2421, 3191 and 3800 or 4810. Prereq: Graduate standing in Applied Mathematics. Cross-listed with MATH 4390. Term offered: fall, spring, summer. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall, Spring, Summer.

MATH 5394 - Experimental Designs (3 Credits)
Designs covered will include: completely randomized, complete block, split plot, incomplete block, factorial and fractional factorial designs. Additionally, power and study design for non-experimental studies will be covered. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of an undergraduate-level course in regression analysis (e.g., MATH 4387). Cross-listed with MATH 4394. Term offered: spring of even years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Spring.

MATH 5410 - Modern Cryptology (3 Credits)
Every other year. Deals with the mathematics that underlies modern cryptology. Topics include: classical cryptology, public and private key cryptosystems, secret sharing schemes, authentication schemes, linear feedback shift registers, discrete logarithm and elliptic curve-based schemes. Note: this course assumes that students have the equivalent of a course in linear algebra (e.g., MATH 3191). Prereq: Graduate standing in Applied Mathematics. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5432 - Computational Graph Theory (3 Credits)
Infrequent. Algorithmic techniques in graph theory and other discrete mathematics areas. Typical topics include: branch-bound algorithms, matching, colorings, domination, min-plus algebra, simulated annealing and related heuristics, NP-completeness theory. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in graph theory (e.g., MATH 4408). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5446 - Theory of Automata (3 Credits)
Infrequent. Studies the relationships between classes of formal languages (regular, context-free, context-sensitive, phrase-structure) and classes of automata (finite-state, pushdown, Turing machines). Additional topics include decidability and computability issues. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in abstract algebra (e.g., MATH 4140). Cross-listed with CSCI 5446. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5490 - Network Flows (3 Credits)
Every other year. Begins with the classical min-cost flow problem, defined on an ordinary network. Other problems, such as shortest path, are also shown in this class. Both theory and algorithms are presented. Extensions include generalized networks, nonlinear costs, fixed charges, multi-commodity flows and additional applications, such as in communications networks. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Term offered: spring of even years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 5576 - Mathematical Foundations of Artificial Intelligence I (3 Credits)
Infrequent. A fundamentals course that complements other approaches, such as in engineering, psychology, and business administration. Here the emphasis is on the mathematical foundations. Topics include logical inference, problem solving, heuristic search, neural nets, analogical reasoning and learning. Models and paradigms also consider different measures of uncertainty. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate course in data structures (e.g., CSCI 2511) and a course in linear algebra (e.g., MATH 3191). Cross-listed with MATH 4576. Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5593 - Linear Programming (3 Credits)
A linear program is an optimization problem that seeks to minimize or maximize a linear function subject to a system of linear in equalities and equations. This course begins with examples of linear programs and variations in their representations. Basic theoretical foundations covered include polyhedra, convexity, linear inequalities and duality. Two classes of solution algorithms are given: simplex methods and interior point methods. The primary emphasis of this course is on mathematical foundations, and applications are used to illustrate the main results. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a course in linear algebra (e.g., MATH 3191). Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall.

MATH 5610 - Computational Biology (3 Credits)
Every other year. Basic introduction and mathematical foundations. Topics include comparative genomics; proteomics; phylogeny; dynamic programming and sequence alignment; gene expression arrays and clustering; Bayesian networks; structure prediction and hidden Markov models. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have some programming experience or the equivalent of a programming course (e.g., CSCI 1410) and linear algebra (e.g., MATH 3191 or 3195). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5660 - Numerical Analysis I (3 Credits)
A first semester course in numerical methods and analysis fundamental to many algorithms encountered in scientific computing, data science, machine learning, and computational models in science and engineering. Rounding errors and numerical stability of algorithms; solution of linear and nonlinear equations; data modeling with interpolation and least-squares; and optimization methods. This course assumes that students have the equivalent of differential and integral calculus (e.g., MATH 2411), linear algebra (e.g., MATH 3191 or 3195), and computer programming (e.g., MATH 1376 or CSCI 1410). Cross-listed with CSCI 4650, 5660, and MATH 4650. Term offered: fall, spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall, Spring.

MATH 5661 - Numerical Analysis II (3 Credits)
A second semester course in numerical methods and analysis fundamental to many algorithms encountered in scientific computing, data science, machine learning, and computational models in science and engineering. Numerical differentiation and integration; random numbers and stochastic modeling; Fast Fourier Transform; data compression; eigenvalues and singular value decompositions with application to regression and dimension reduction. This course assumes that students have the equivalent of differential and integral calculus (e.g., MATH 2411), linear algebra (e.g., MATH 3191 or 3195), and computer programming (e.g., MATH 1376 or CS 1410). Cross-listed with MATH 4660, CSCI 4660 and 5661. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 5674 - Parallel Computing and Architectures (3 Credits)
Infrequent. Examines a range of topics involved in using parallel operations to improve computational performance. Parallel architectures, parallel algorithms, parallel programming languages, interconnection networks, and their relation to specific computer architectures. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a course in numerical analysis (e.g., MATH 4650). Cross-listed with MATH 4674. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5718 - Applied Linear Algebra (3 Credits)
Topics include: Vector spaces, practical solution of systems of equations, projections, eigenvalues and eigenvectors, unitary transformations, Schur QR, singular value decompositions, similarity transformations, Jordan forms, and positive definite matrices. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in linear algebra (e.g., MATH 3191). Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall.

MATH 5733 - Partial Differential Equations (3 Credits)
Infrequent. Initial/Boundary value problems for first-order, wave, heat and Laplace Equations; maximum principles; Fourier Series and applications. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate sequence in calculus (e.g., through MATH 2421) and differential equations (e.g., MATH 3200 or 3195). Cross-listed with MATH 4733. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 5779 - Math Clinic (3 Credits)
The clinic is intended to illustrate the applicability and utility of mathematical concepts. Research problems investigated originate from a variety of sources--industry, government agencies, educational institutions, or nonprofit organizations. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Cross-listed with MATH 4779. Term offered: fall, spring. Repeatable. Max Hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall, Spring.

MATH 5791 - Continuous Modeling (3 Credits)
Every other year. Surveys mathematical problems that arise in natural sciences and engineering. Topics may include population models, epidemic models, mechanics, heat transfer and diffusion, tomography, pharmaco-kinetics, traffic flow, fractal models, wave phenomena, and natural resource management. Most models discussed are based on differential and integral equations. Emphasis is formulation and validation of models as well as methods of solution. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of undergraduate-level courses in differential equations and linear algebra (e.g., MATH 3200 and 3191). Cross-listed with MATH 4791. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5792 - Probabilistic Modeling (3 Credits)
Every other year. Markov chains; Poisson processes, continuous time Markov chains, elementary topics in queuing theory, and some mathematical aspects of Monte Carlo simulation, including random variate generation, variance reduction, and output analysis. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate-level course in probability (e.g., MATH 4810) and some programming experience. Cross-listed with MATH 4792. Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall.

MATH 5793 - Discrete Math Modeling (3 Credits)
Every other year. Focuses on the use of graph theory and combinatorics to solve problems in a wide variety of disciplines. Applications are selected from computer science, communication networks, economics, operations research, and the social, biological and environmental sciences. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of an undergraduate course in linear algebra (e.g., MATH 3191) and graph theory (e.g., MATH 4408). Cross-listed with MATH 4793. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5794 - Optimization Modeling (3 Credits)
Every other year. Principles of model formulation and analysis are developed by presenting a wide variety of applications, both for natural phenomena and social systems. Examples of optimization models to represent natural phenomena include principles of least time and energy. Examples in social systems include resource allocation, environmental control and land management. Specific applications vary, but are chosen to cover a wide scope that considers dichotomies, such as discrete vs. continuous, static vs. dynamic, and deterministic vs. stochastic. Some computer modeling language (like GAMS) is taught. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. : This course assumes that students have the equivalent of a sequence in calculus (e.g., through MATH 2421) and linear algebra (e.g., MATH 3191). Cross-listed with MATH 4794. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 5830 - Applied Statistics (3 Credits)
Review of estimation, confidence intervals and hypothesis testing; ANOVA; categorical data analysis; non-parametric tests; linear and logistic regression. Restriction: Restricted to Graduate and Graduate Non-Degree majors. Note: This course assumes that students have the equivalent of an introductory course in statistics (e.g., MATH 2830). No co-credit with MATH 4387 or 5387 and doesn't count for Math degrees. Cross-listed with MATH 4830. Term offered: spring. Max hours: 3 Credits.
Grading Basis: Letter Grade
Restriction: Restricted to Graduate and Graduate Non-Degree Majors
Typically Offered: Spring.

MATH 5840 - Independent Study (1-3 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. Repeatable. Max Hours: 9 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 9.
Prereq: Graduate standing in Applied Mathematics

MATH 5880 - Directed Research (1-6 Credits)
Students will engage in original research projects supervised and mentored by faculty. Students must work with faculty prior to registration to develop a proposal for their project and receive permission to take this course. Repeatable. Max Hours: 6 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 6.

MATH 5939 - Internship (1-6 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Repeatable. Max Hours: 9 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 9.
Prereq: Graduate standing in Applied Mathematics

MATH 5950 - Master's Thesis (1-8 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments, and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. Repeatable. Max hours: 8 Credits. No co-credit with MATH 5960 or MATH 6960.
Grading Basis: Letter Grade with IP
Repeatable. Max Credits: 8.
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Additional Information: Report as Full Time.

MATH 5960 - Master's Project (1-8 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments, and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. No cocredit with MATH 5950 or MATH 6960.
Grading Basis: Letter Grade with IP
Repeatable. Max Credits: 8.
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Additional Information: Report as Full Time.

MATH 6023 - Topics in Discrete Math (3 Credits)
Topics may include graph theory, combinatorics, matroid theory, combinatorial matrix theory, finite geometry, design theory, and discrete algorithms. Note: Since topic varies by semester, students may register for this course more than once. Note: students should obtain permission from the instructor prior to enrolling in this course. Prereq: Graduate standing in Applied Mathematics. Repeatable. Max Hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.
Prereq: Graduate standing in Applied Mathematics

MATH 6101 - Uncertainty Quantification (3 Credits)
The field of uncertainty quantification is evolving rapidly due to increasing emphasis on models of physical and biological systems that have quantified uncertainties for large-scale applications, novel algorithm development, and new computational architectures that facilitate implementation of these algorithms. In this course, we develop the basic concepts, theory, and algorithms necessary to quantify input and response uncertainties for a variety of simulation models. The topics will include concepts from probability and statistics, parameter selection techniques, frequentist and Bayesian model calibration, propagation of uncertainties, quantification of model discrepancy, surrogate model construction, and local and global sensitivity analysis. Note: A basic knowledge of probability, linear algebra, ordinary and partial differential equations, and introductory numerical analysis techniques is assumed. Coursework will typically consist of projects. Prereq: Graduate standing in Applied Mathematics or Statistics. AMENMS/PHD/STAT-MS. Recommended preparation MATH 5070, MATH 5718, MATH 5660, MATH 5733. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 6131 - Real Analysis (3 Credits)
Every other year. Lebesque measure and integration, general measure and integration theory, Radon-Nikodyn Theorem, Fubini Theorem. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a two semester course in undergraduate analysis or advanced calculus (e.g. MATH 4310 and 4320) or introductory graduate-level coursework in analysis (e.g. MATH 5070). Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall.

MATH 6330 - Workshop in Statistical Consulting (3 Credits)
Students participate as consultants in a drop-in consulting service operated by the department. Seminars provide students with supervised experience in short term statistical consulting. Note: Since problems vary each semester, students may register for this course more than once. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of graduate-level coursework in regression analysis (e.g. MATH 5387). Term offered: fall. Repeatable. Max Hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Fall.

MATH 6360 - Exploratory Data Analysis (3 Credits)
Every other year. Philosophy and techniques associated with exploratory (vs. confirmatory) data analysis, both as originally presented (John Tukey) and current computer-based implementations. Graphical displays, robust-resistant methods (lines, two-way fits), diagnostic plots, standardization. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have prior coursework in statistics. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 6376 - Statistical Computing (3 Credits)
Computationally-intensive methods in statistics, including random number generation and Monte Carlo methods, data partitioning and re-sampling, numerical and graphical methods, nonparametric function estimation, statistical models and data mining methodology, analysis of large data sets. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have prior coursework in statistics (e.g. MATH 4820 or 4830 or 3382) and regression analysis (e.g. MATH 4387). Cross-listed with MATH 7376. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 6380 - Stochastic Processes (3 Credits)
Every other year. Markov processes in discrete and continuous time, renewal theory, martingales, Brownian motion, branching processes, and stationary processes. Applications include queuing theory, performance evaluation of computer and communication systems and finance. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of undergraduate-level coursework in linear algebra (e.g. MATH 3191) and ordinary differential equations (e.g. MATH 3200), along with undergraduate-level coursework in probability (e.g. MATH 4810). Term offered: fall of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 6384 - Spatial Data Analysis (3 Credits)
This course will cover various statistical methods for spatial data. This will include assessing cluster identification for point process and regional data, as well as quantifying spatial dependence and making predictions for regional and geostatistical spatial data. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Term offered: fall of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Fall.

MATH 6388 - Statistical and Machine Learning (3 Credits)
This course covers a variety of statistical and machine learning methods. Both supervised and unsupervised methods are covered with an emphasis on model training and error estimation. Topics include penalized regression, principal components, k-nearest neighbors, clustering, and neural networks. Additional higher-level topics such as random forests, support vector machines, and boosting are also covered as time permits. Students will gain exposure to high performance computing by working on a Linux cluster. Prereq: Graduate standing in Statistics or Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in regression analysis (e.g. MATH 5387). Term offered: fall of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Fall.

MATH 6395 - Multivariate Methods (3 Credits)
Every other year. Multivariate distributions, hypothesis testing and estimation. Multivariate analysis of variance, discriminant analysis, multidimensional scaling, factor analysis, principal components. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of graduate-level coursework in regression analysis (e.g. MATH 5387). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 6398 - Calculus of Variations and Optimal Control (3 Credits)
Infrequent. Standard variational problems (geodesic, time-of-transit, isoperimetric, surface, area), Euler-Lagrange equations, variational principles in mechanics, optimal control problems, necessary conditions for optimality, Pontryagin principle. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a two semester course in undergraduate analysis or advanced calculus (e.g. MATH 4310 and 4320) or introductory graduate-level coursework in analysis (e.g. MATH 5070). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 6404 - Applied Graph Theory (3 Credits)
Every other year. Emphasis on graph theory. Topics will include trees, diagraphs and networks, intersection graphs, coloring, clique coverings, distance, paths and cycles. Topics are motivated by applications. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Term offered: fall. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Fall.

MATH 6595 - Nonlinear Programming (3 Credits)
Every other year. Introduces fundamental algorithms and theory for nonlinear optimization problems. Topics include Newton, quasi-Newton and conjugate direction methods; line search and trust-region methods; active set, penalty and barrier methods for constrained optimization; convergence analysis and duality theory. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a two semester course in undergraduate analysis (e.g. MATH 4310 and 4320) and graduate-level coursework in linear algebra (e.g. MATH 5718). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 6653 - Introduction to Finite Element Methods (3 Credits)
Every other year. The Finite Element Method (FEM) is introduced as a generic tool for the approximation of partial differential equations that model engineering and physics problems of interest. Elliptic, hyperbolic, and parabolic equations are solved with FEM. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in numerical analysis (e.g. MATH 5660). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 6735 - Continuum Mechanics (3 Credits)
Every other year. Indicial notation. Eulerian and Lagrangian coordinates. Deformation, strain, strain rate, stress. Conservation of mass, momentum, and energy. Exploitation of entropy production inequality to obtain constitutive equations for elastic, viscous, visco elastic, plastic, or porous materials. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of undergraduate-level coursework in linear algebra (e.g. MATH 3191) and ordinary differential equations (e.g. MATH 3200). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 6840 - Independent Study (1-3 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. Repeatable. Max Hours: 3 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 3.
Prereq: Graduate standing in Applied Mathematics

MATH 6960 - Research Methods in Mathematics and Statistics (3 Credits)
The goal of the course is to guide students through the process of performing rigorous mathematical and statistical research. Topics include performing a proper literature review, developing technical writing skills, and learning best practices regarding oral presentations. Students will discuss their ongoing research projects in groups and individually with the instructor, write a research paper, and present their results in a classroom seminar. Master's students should be entering their final year of coursework. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permissions. No co-credit with MATH 5950, MATH 5960, or ECON 6073. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7101 - Topology (3 Credits)
Every other year. Topological spaces, compactness, separation properties and connectedness. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of a two semester undergraduate sequence in analysis or advanced calculus (e.g. MATH 4310 and 4320) or a graduate-level course in analysis (e.g. MATH 5070). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7132 - Functional Analysis (3 Credits)
Every other year. Linear metric and topological spaces, duality, weak topology, spaces of functions, linear operators, compact operators, elements of spectral theory, and operator calculus. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate level coursework in real analysis (e.g. MATH 6131). Term offered: spring of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 7376 - Statistical Computing (3 Credits)
Computationally-intensive methods in statistics, including random number generation and Monte Carlo methods, data partitioning and re-sampling, numerical and graphical methods, nonparametric function estimation, statistical models and data mining methodology, analysis of large data sets. Note: This course assumes that students have prior coursework in statistics (e.g. MATH 4820 or 4830 or 3382) and regression analysis (e.g. MATH 4387). Cross-listed with MATH 6376. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Cross-listed with MATH 6376. Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7381 - Mathematical Statistics I (3 Credits)
Every other year. Mathematical theory of statistics. Parametric inference: discrete and continuous distributions, methods of parameter estimation, confidence intervals. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note:This course assumes that students have the equivalent of undergraduate-level coursework in linear algebra (e.g. MATH 3191) and statistics (MATH 5320). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7382 - Mathematical Statistics II (3 Credits)
Every other year. (Continuation of MATH 7381.) Hypothesis testing, robust estimation, tolerance intervals, nonparametric inference, sequential methods. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: This course assumes that students have the equivalent of advanced graduate level coursework in mathematical statistics (e.g. MATH 7381). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7384 - Mathematical Probability (3 Credits)
Every other year. Measurable spaces, probability measures, random variables, conditional expectations and martingales. Convergence in probability, almost sure convergence, convergence in distribution, limit theorems (law of large numbers, central limit theorem, laws of iterated logarithm). Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of undergraduate-level coursework in probability (e.g. MATH 4810) and graduate-level coursework in analysis (e.g. MATH 5070 or 6131). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7385 - Stochastic Differential Equations (3 Credits)
Brownian motion, Ito integral, Ito formula, Dynkin's formula, stochastic optimal control, boundary value problems, Girsanov theorem, mathematical finance, optimal stopping. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in mathematical probability (e.g. MATH 7384). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7386 - Monte Carlo Methods (3 Credits)
This course introduces Monte Carlo integration, variance reduction methods, quasi-Monte Carlo, Markov chain Monte Carlo, Metropolis-Hastings algorithm, Gibbs sampler, simulated annealing, expectation-maximization algorithm, sequential Monte Carlo methods. Prereq: Graduate standing in Applied Mathematics or Statistics. AMENMS/PHD/STAT-MS. Recommended preparation: MATH 5310 and MATH 5320. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7393 - Bayesian Statistics (3 Credits)
Prior and posterior distributions, conjugate models, single and multiparameter models, hierarchical models, numerical methods for evaluating posteriors, Monte Carlo methods, and Markov chain Monte Carlo. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Programming experience is strongly recommended. Term offered: spring of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS
Typically Offered: Spring.

MATH 7397 - Nonparametric Statistics (3 Credits)
Every three years. Statistical inference without strong model assumptions. Hypothesis testing and estimation using permutations and ranks, analysis of variance, and nonparametric model fitting. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7405 - Advanced Graph Theory (3 Credits)
Continuation of MATH 6404. Topics to be covered include: trees and optimization, encoding and embedding of graphs, generalized colorings and applications, perfect graphs, extremal problems, substructures, connectedness' and cycles. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in graph theory (e.g. MATH 6404). Term offered: spring of even years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 7409 - Applied Combinatorics (3 Credits)
Every other year. Emphasis is on enumerative combinatorics. Topics include multinomial coefficients, generating functions, SDRs, Polya's enumeration theory, pigeon-hole principle, inclusion/exclusion and Moebius inversion of finite posets. Topics may also include introduction to designs and finite geometry. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7410 - Combinatorial Structures (3 Credits)
Every other year. Finite combinatorial structures; existence, construction and applications. Topics include Latin squares, Hadamard matrices, block designs, finite geometries and extremal and non-constructive combinatorics. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in combinatorics (e.g. MATH 7409). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7413 - Modern Algebra I (3 Credits)
Every other year. Groups, rings and ideals, integral domains. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of undergraduate level coursework in abstract algebra (e.g. MATH 4140). It is recommended that students take MATH 5718 during the same semester as MATH 7413. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7414 - Modern Algebra II (3 Credits)
Every other year. Field theory, Galois theory, Modules over rings, especially over integral domains. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear algebra (e.g. MATH 5718) and abstract algebra (e.g. MATH 7413). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7419 - Mathematical Coding Theory (3 Credits)
Error correcting codes are used to recapture information that has been distorted in some transmission process. Various coding schemes use block codes obtained from algebraic, geometric and combinatorial structures. Topics include: fundamentals, linear, Reed-Muller, Golay, cyclicand BCH codes. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear algebra (e.g. MATH 5718). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7421 - Projective Geometry (3 Credits)
Every other year. Synthetic and algebraic development of projective spaces. Collineation groups, representation theorems, quadratic sets and applications. Emphasis is on finite projective spaces. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear algebra (e.g. MATH 5718) and combinatorics (e.g. MATH 7409). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7593 - Advanced Linear Programming (3 Credits)
Every three years. A Ph.D. level course that goes deeper into linear programming, starting from where a graduate-level course (5593) ends. Topics include advanced sensitivity analysis, sparse matrix techniques, and special structures. Additional topics, which vary, include deeper analysis of algorithms, principles of model formulation and solution analysis. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear programming (e.g. MATH 5593). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7594 - Integer Programming (3 Credits)
Every three years. A Ph.D. level course that uses linear programming (5593), especially polyhedral theory, to introduce concepts of valid inequalities and superadditivity. Early group-theoretic methods by Gomory and Chvatal's rounding function are put into modern context, including their role in algorithm design and analysis. Duality theory and relaxation methods are presented for general foundation and analyzed for particular problem classes. Among the special problems considered are knapsack, covering, partitioning, packing, fix-charge, traveling salesman, generalized assignment matchings. Matroids are introduced and some greedy algorithms are analyzed. Additional topics, which vary, include representability theory, heuristic search and complexity analysis. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear programming (e.g. MATH 5593). Term offered: spring of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 7595 - Advanced Nonlinear Programming (3 Credits)
Every three years. Focuses primarily on the fundamental theory of nonlinear programming. Topics include convex analysis, optimality criteria, Lagrangian and conjugate duality, stability and sensitivity analysis. Other topics vary depending on the research interests of the instructor. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework addressing computational methods in nonlinear programming (e.g. MATH 6595). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7663 - Finite Difference Methods for Partial Differential Equations (3 Credits)
Every other year. Consistency, stability, and convergence for difference schemes. Derivations based on Taylor series and finite series. Methods for parabolic and hyperbolic initial value problems and initial-boundary-value problems, elliptic boundary-value problems, some nonlinear problems. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in numerical analysis (e.g. MATH 5070) and partial differential equations (e.g. MATH 5733). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7665 - Numerical Linear Algebra (3 Credits)
Every other year. Solution of linear equations, eigenvector and eigenvalue calculation, matrix error analysis, orthogonal transformation, iterative methods. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in numerical analysis (e.g. MATH 5660) and linear algebra (e.g. MATH 5718). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7667 - Introduction to Approximation Theory (3 Credits)
Every other year. Linear normed and Banach spaces, convexity, existence and uniqueness of best approximations, least square approximation and orthogonal polynomials, Chebyshev approximation by polynomials and other related families, splines. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in analysis (e.g. MATH 5070) and linear algebra (e.g. MATH 5718). Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 7821 - Topics in Projective Geometry (3 Credits)
Infrequent. Advanced topics in projective geometry. Topics may include finite projective planes, free projective planes, derivation, collineation groups, higher dimensional projective spaces, ovals and oviods. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in projective geometry (e.g. MATH 7821). Repeatable. Max Hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7822 - Topics in Linear Algebra (3 Credits)
Infrequent. Topics may include canonical forms, bilinear and quadratic forms, and combinatorial matrix theory. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in linear algebra (e.g. MATH 5718). Repeatable. Max Hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7823 - Topics in Discrete Math (3 Credits)
Infrequent. Advanced topics in discrete mathematics; will change from semester to semester. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: Students should contact the course instructor to determine the course focus, and to determine if any prior undergraduate- or graduate-level coursework is assumed. Repeatable. Max Hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7824 - Topics in Computational Mathematics (3 Credits)
Infrequent. Topics include methods for differential equations, numerical optimization, approximation theory, inverse problems, and Fourier analysis. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: Students should contact the course instructor to determine the course focus, and to determine if any prior undergraduate- or graduate-level coursework is assumed. Repeatable. Max Hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7825 - Topics in Optimization (3 Credits)
Infrequent. Some topics are extensions of those introduced in MATH 6595, while other topics are new. Examples of topics are: duality, stability, sensitivity, consistency, redundancy, principles of optimality, control theory, calculus of various global (non-convex) optimization and model reformulation. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: Students should contact the course instructor to determine the course focus, and to determine if any prior undergraduate- or graduate-level coursework is assumed. Repeatable. Max hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7826 - Topics in Probability and Statistics (3 Credits)
Infrequent. Topics may include generalized linear models, information theory, robust methods, spatial statistics, sequential analysis, Monte Carlo methods, queuing theory. Note: Since topics vary each semester, students may register for this course more than once. Prereq: Graduate standing in Applied Mathematics or Statistics or instructor permission. AMEN-MS/PHD/STAT-MS. Note: Students should contact the course instructor to determine the course focus, and to determine if any prior undergraduate- or graduate-level coursework is assumed. Repeatable. Max hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics or Statistics. AMEN-MS/PHD/STAT-MS

MATH 7827 - Topics in Applied Mathematics (3 Credits)
Infrequent. Topics include problems in differential equations, optimization, mathematical modeling, Fourier analysis and approximation theory. Note: Since topics vary each semester, students may register for this course more than once. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Repeatable. Max Hours: 48 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 48.
Prereq: Graduate standing in Applied Mathematics

MATH 7840 - Independent Study (1-3 Credits)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. Repeatable. Max Hours: 3 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 3.
Prereq: Graduate standing in Applied Mathematics

MATH 7921 - Readings in Mathematics (1 Credit)
Annual. Seven readings courses are offered regularly primarily for Ph.D. students at the research level in the designated fields. The seminar format requires significant student participation. Prereq: permission of instructor. Department consent required. Repeatable. Max hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.

MATH 7922 - Rdgs:Math Fndts-Cmptr Sc (1 Credit)
Department consent required. Repeatable. Max hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.

MATH 7923 - Readings: Discrete Mathematics (1 Credit)
Department consent required. Repeatable. Max hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.

MATH 7924 - Rdgs:Comp Mathematics (1 Credit)
Department consent required. Repeatable. Max Hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.

MATH 7925 - Readings: Optimization (1 Credit)
Department consent required. Repeatable. Max hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.

MATH 7926 - Rdgs:Applied Prob/Stats (1 Credit)
Note: Students must submit a special processing form completely filled out and signed by the student and faculty member, describing the course expectations, assignments and outcomes, to the Graduate School for approval. Prereq: Graduate standing in Applied Mathematics or Statistics and instructor permission. Repeatable. Max Hours: 99 Credits.
Grading Basis: Letter Grade
Repeatable. Max Credits: 99.
Prereq: Graduate standing in Applied Mathematics

MATH 7927 - Rdgs:Comp/Math Biology (1 Credit)
Department consent required. Max hours: 1 Credits.
Grading Basis: Letter Grade

MATH 8660 - Mathematical Foundations of Finite Element Methods (3 Credits)
Every other year. Theoretical foundations of finite element methods for elliptic boundary value problems, Sobolev spaces, interpolations of Sobolev spaces, variational formulation of elliptic boundary-value problems, basic error, estimates, applications to elasticity, practical aspects of finite element methods. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in finite element methods (e.g. MATH 6653) or equivalent programming experience, and graduate-level coursework in analysis or functional analysis (e.g. MATH 6131 or MATH 7132). Term offered: spring of odd years. Max hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics
Typically Offered: Spring.

MATH 8664 - Iterative Methods in Numerical Linear Algebra (3 Credits)
Every other year. Preconditioned iterative methods for linear systems and eigen problems, conjugate gradients, multigrid and domain decomposition. Prereq: Graduate standing in Applied Mathematics or permission of the instructor. Note: This course assumes that students have the equivalent of graduate-level coursework in numerical analysis (e.g. MATH 5660) and numerical linear algebra (e.g. MATH 7665). Max Hours: 3 Credits.
Grading Basis: Letter Grade
Prereq: Graduate standing in Applied Mathematics

MATH 8990 - Doctoral Dissertation (1-10 Credits)
Only for students working on their Ph.D. research. Department consent required. Repeatable. Max hours: 50 Credits.
Grading Basis: Letter Grade with IP
Repeatable. Max Credits: 50.
Additional Information: Report as Full Time.