Department of Applied Mathematics

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Chair:
Fred J. Hickernell

Director, Graduate Studies:
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The Department of Applied Mathematics puts mathematics to work solving problems in science, engineering and society. Applied mathematicians investigate a wide variety of topics, such as how to construct methods for multi-criteria decision making (requiring discrete mathematics and statistics), predicting how financial markets will behave (requiring probability/statistics, analysis and optimization), and understanding how liquids flow around solids (requiring computational methods and analysis). Our programs focus on four areas of modern applied mathematics: applied analysis, computational mathematics, discrete applied mathematics, and stochastics. More detailed descriptions of these areas follow.

Degrees Offered

Master of Science in Applied Mathematics
Doctor of Philosophy in Applied Mathematics
Master of Mathematical Finance (collaborative program with the Stuart School of Business)

Research Facilities

The department provides students with office space equipped with computers and full access to the university's computer and library resources. The department also has a 18-processor Beowulf cluster for research purposes.

Research and Program Areas

The research and teaching foci of the Department of Applied Mathematics at IIT are primarily in four areas of modern applied mathematics: applied analysis, computational mathematics, discrete applied mathematics, and stochastics. These areas are briefly described in the following subsections; faculty with primary and secondary interests and expertise are listed for each of these areas.

Applied Analysis

Applied analysis is one of the foundations for interdisciplinary applied mathematics. The principles of (functional) analysis are applied to such areas as partial differential equations, dynamical systems and numerical analysis.

The basic framework, concepts and techniques of modern mathematical analysis are essential for modeling, analysis and simulation of complicated phenomena in engineering and science. Applying the ideas and methods of modern mathematical analysis to such problems has been a thoroughly interdisciplinary effort.

Research and teaching within the applied analysis group at IIT concentrates on development and application of new techniques for investigating numerous phenomena in engineering and science. In particular, members of the group do research in nonlinear dynamics, approximation theory, numerical analysis, fluid dynamics, materials science, viscoelastic and polymeric fluid flows, biological science, quantum mechanics and electro-dynamics, solid mechanics, financial engineering and other disciplines.

Primary interests: Abarji, Bielecki, Duan, Edelstein, Frank

Secondary interests: Bernstein, Erber, Fasshauer, Li, Lubin, Nair, Rempfer, Wendland

Computational Mathematics

The use of computation/simulation as a third alternative to theory and experimentation is now common practice in many branches of science and engineering. Many scientific problems that were previously inaccessible have seen tremendous progress from the use of computation (e.g., many-body simulations in physics and chemistry, simulation of semi-conductors, etc.). Researchers and scientists in these areas must have a sound training in the fundamentals of computational mathematics and become proficient in the use (and development) of new algorithms and analytical techniques as they apply to modern computational environments.

Research and teaching within the computational mathematics group at IIT concentrates on basic numerical analysis, as well as development of new computational methods used in the study and solution of problems in the applied sciences and engineering. In particular, members of the group do research on complexity theory, the finite element method, meshfree methods, multiscale and multilevel methods, Monte Carlo and quasi-Monte Carlo methods, numerical methods for deterministic and stochastic ordinary and partial differential equations, computational fluid dynamics, computational materials science, computer-aided geometric design and parallel computation.

Primary interests: Fasshauer, Hickernell, Li, Wendland

Secondary interests: Bernstein, Duan, Fang, McMorris, Rempfer

Discrete Applied Mathematics

Discrete applied mathematics is a fairly young branch of mathematics and is concerned with using combinatorics, graph theory, optimization, and portions of theoretical computer science to attack problems in engineering as well as the hard and soft sciences.

Research interests in the discrete applied mathematics group at IIT are in discrete methods in computational and mathematical biology, intersection graphs and their applications, discrete location theory, voting theory applied to data analysis, graph drawing, random geometric graphs, communication networks, coding theory, low discrepancy sequences, algorithm design and analysis.

Primary interests: Ellis, Kaul, McMorris, Pelsmajer

Secondary interests: Frank, Hickernell

Stochastics

Stochastics at IIT includes traditional statistics (the methods of data analysis and inference) and probability (the modeling of uncertainty and randomness). However, also included are other areas where stochastic methods have been becoming more important in recent years such as finite and infinite dimensional stochastic processes, stochastic integration, stochastic dynamics, stochastic partial differential equations, probabilistic methods for analysis, mathematical finance and discrete mathematics, computational methods for stochastic systems, etc.

The current research and teaching interests in the stochastic analysis group at IIT include asymptotics in statistics, experimental design, computational statistics, stochastic calculus and probability theory, stochastic dynamical systems, stochastic control, stochastic partial differential equations and statistical decision theory.

Primary interests: Adler, Bielecki, Duan, Fang, Heller, Hickernell

Secondary interests: Ellis, Frank, Kaul, McMorris

Faculty

Andre Adler, Associate Professor of Applied Mathematics. Ph.D., University of Florida. Asymptotics in statistics, probability and statistical inference.

Snejana Abarji, Associate Professor of Applied Mathematics. Ph.D., Landau Institute. Applied Mathematics and Applied Analysis (nonlinear partial differential equations, stochastic differential equations, dynamical systems); multi-scale phenomena; Mathematical Biology.

Barry Bernstein, Professor of Applied Mathematics and Chemical Engineering. Ph.D., Indiana University. Mechanical and thermodynamic behavior of materials, material processing problems, such as extrusion and molding of polymer; theory of fluids treating thermodynamics as well as the mechanics of such media; computational work on polymeric fluid flows, finite element formulation known as flucode; tracer analysis of blood circulation and of recycle reactors.

Thomasz R. Bielecki, Associate Professor of Applied Mathematics. Ph.D., Warsaw School of Economics. Mathematical finance, stochastic control, stochastic analysis, probability and random processes, quantitative methods for risk management in finance and insurance.

Jinqiao (Jeffrey) Duan, Professor of Applied Mathematics. Ph.D., Cornell University. Stochastic dynamical systems; stochastic partial differential equations; nonlinear dynamical systems; modeling, analysis, simulation and prediction of random, complex & multiscale phenomena in engineering and science (geophysical and environmental systems, etc.)

Faculty (continued)

Warren Edelstein, Professor of Applied Mathematics. Ph.D., Brown University. Analysis of linear viscoelasticity and nonlinear creep, numerical analysis of flow-induced vibrations in tubes conveying fluids, numerical solution of boundary value problems arising in the quantum mechanics of semiconductors. Computational mechanics and mathematics of finance.

Robert B. Ellis, Assistant Professor of Applied Mathematics. Ph.D., University of California at San Diego. Combinatorics; spectral, random and algebraic graph theory; probabilistic methods; coding theory; and combinatorial algorithms.

Thomas Erber, Distinguished Professor of Applied Mathematics and Physics. Ph.D., University of Chicago. Quantum electrodynamics in intense magnetic fields; classical electrodynamics; the quantum mechanics of single trapped atoms; magnetic and mechanical hysteresis; metal fatigue; structure and evolution of complex physical systems; sonoluminescence.

Kai-Tai Fang, Distinguished Research Professor of Applied Mathematics. Graduate Studies, Academia Sinica. Multivariate analysis, experimental design, distribution theory, applications of number-theoretic methods in statistics, data mining and applications to Chinese medicine.

Gregory Fasshauer, Associate Professor and Associate Chair of Applied Mathematics. Ph.D., Vanderbilt University. Approximation theory, numerical analysis, meshfree methods with applications to multivariate scattered data approximation and the solution of partial differential equations. Computer-aided geometric design and bivariate splines.

Maurice J. Frank, Professor of Applied Mathematics, Ph.D., Illinois Institute of Technology. Functional equations, associativity and related equations, iterative equations and systems; probability distribution theory, probabilistic geometry; iteration, nonlinear dynamics.

Barbara Heller, Research Associate Professor of Applied Mathematics. Ph.D., University of Chicago. Theoretical and applied statistics, data analysis in the physical and biological sciences, goodness-of-fit tests, computer simulations of spatial distributions.

Fred J. Hickernell, Professor and Chair of Applied Mathematics, Ph.D., Massachusetts Institute of Technology. Computational mathematics, numerical approximation of integrals and functions, Monte Carlo and quasi-Monte Carlo methods, low information-based complexity theory, design of laboratory and computer experiments, computational finance.

Hemanshu Kaul, Assistant Professor of Applied Mathematics. Ph.D., University of Illinois at Urbana-Champaign. Graph Theory and Combinatorics, Discrete Optimization and Operations Research, Probabilistic Models and Methods in Discrete Mathematics.

Xiaofan Li, Associate Professor of Applied Mathematics and Director of Graduate Studies, Ph.D., University of California, Los Angeles. Computational fluid dynamics, computational materials science. Boundary integral method, moving-boundary value problems. Suspension of particles, phase transformation in materials science.

Arthur Lubin, Associate Professor of Applied Mathematics. Ph.D., University of Wisconsin, Madison. Commuting contractions in Hilbert space, spectral theory, models for analytic functions, linear system theory.

David Maslanka, Senior Lecturer and Director of Academic Resource Center. B.A., St. Xavier University; M.S., Ph.D., Illinois Institute of Technology.

F. R. McMorris, Professor of Applied Mathematics, Computer Science, and Dean of the College of Science and Letters. Ph.D., University of Wisconsin, Milwaukee. Discrete applied mathematics, computational and mathematical biology, classification theory, location theory.

Sudhakar E. Nair, Professor of Mechanical and Aerospace Engineering and Applied Mathematics, and Associate Dean of Academic Affairs, Graduate College. Ph.D., University of California, San Diego. Solid mechanics, elastic and inelastic behavior of materials, applied mathematics, moving boundary problems, wave propagation in anisotropic media.

Michael J. Pelsmajer, Assistant Professor of Applied Mathematics. Ph.D., University of Illinois, Urbana-Champaign. Graph theory, combinatorics, communication networks.

Dietmar Rempfer, Associate Professor of Mechanical and Aerospace Engineering and Applied Mathematics. Ph.D., Habilitation, Universität Stuttgart. Fluid mechanics, especially theoretical studies of transitional and turbulent shear flows in open systems; numerical fluid mechanics; modeling for environmental and urban fluid mechanics; coherent structures in turbulent flows; control of transitional and turbulent wall layers; nonlinear dynamical systems.

Susan S. Sitton, Assistant Provost for Retention and Senior Lecturer. B.A., Grinnell College; M.S., Northwestern University; Ph.D. Illinois Institute of Technology.

Holger Wendland, Associate Professor of Applied Mathematics. Ph.D., University of Göttingen. Meshless methods, radial basis functions, scattered data approximation, fluid-structure interaction, kernel learning.

Admission Requirements

Cumulative undergraduate GPA minimum: 3.0/4.0
GRE score minimum:
For tests taken prior to Oct.1, 2002, M.S./Ph.D.: 1500 (combined)
For tests taken on or after Oct.1, 2002, M.S.: 1100 (quantitative + verbal) 2.5 (analytical writing)
For tests taken on or after Oct.1, 2002, Ph.D.: 1100 (quantitative + verbal) 3.0 (analytical writing)
TOEFL minimum: 550/213*
At least two letters of recommendation

Admission to the professional master's program in Mathematical Finance requires a bachelor's degree in mathematics, engineering, or equivalent, with a minimum cumulative GPA of 3.0/4.0. TOEFL scores (if required) must have a minimum score of 600/213*. A professional statement of goals/objectives (2 pages) and a curriculum vitae must be submitted. Two letters of recommendation are required (at least two must be from academia, the third may be from industry). An interview may also be required.

Typically, admitted students score at least 700 on the quantitative portion of the GRE and at least 3.0 on the analytical portion. However, meeting the minimum or typical GPA test-score requirements does not guarantee admission. GPA and test scores are just two of several important factors considered for admission to the program, including grades in mathematics courses, letters of recommendation and the student's overall record of achievements.

Admission to the Master of Science and the Ph.D. program normally requires a bachelor's degree in mathematics or applied mathematics. Candidates whose degree is in another field (for example, computer science, physics, or engineering) and whose background in mathematics is strong are also eligible for admission and are encouraged to apply. Candidates in the Ph.D. program must also have demonstrated the potential for conducting original research in applied mathematics. Students must remove deficiencies in essential undergraduate courses that are prerequisites for the degree program, in addition to fulfilling all other degree requirements.

The director of graduate studies serves as temporary academic adviser for all newly admitted graduate students until an appropriate faculty member is selected as the adviser. Students are responsible for following all departmental procedures as well as the general requirements of the Graduate College.

* Paper-based test score/computer-based test score.

Master of Mathematical Finance (MMF)

(Collaborative Program with the Stuart School of Business)
21.6 quarter credits
18 semester credits

The objective of the MMF program is to provide individuals interested in pursuing careers in financial risk management with advanced education in theoretical, computational and business aspects of relevant quantitative methodologies. This is a collaborative program between the Stuart School of Business (Stuart GSB) and the Applied Mathematics Department (AM) and as such, it will give the students the chance to benefit from the strength of both units.

Required Courses

MSF 571	Computational Finance I	3.6 Qtr. Credits
MSF 572	Computational Finance II	3.6 Qtr. Credits
MSF 551	Futures, Options and OTC Derivatives	3.6 Qtr. Credits
MATH 542	Stochastic Processes	3 Sem. Credits
MATH 548	Mathematical Finance I	3 Sem. Credits
MATH 565	Monte-Carlo Methods in Finance	3 Sem. Credits
MATH 582	Mathematical Finance II	3 Sem. Credits
MATH 586	Theory and Practice of Fixed Income Models	3 Sem. Credits

Total 10.8 Quarter Credits and 15 Semester Creditss

Elective Courses

A Minimum of four additional courses including: a minimum of one MATH or CS class must be selected and a minimum three FM or MSF courses must be selected.

FM 530	Visual Basic and Databases for Financial Markets	3.6 Qtr. Credits
MSF 522	Financial Modeling I	3.6 Qtr. Credits
MSF 523	Financial Modeling II	3.6 Qtr. Credits
MSF 561	Financial Time Series Analysis	3.6 Qtr. Credits
MSF 562	Econometric Analysis	3.6 Qtr. Credits
MSF 573	Computational Finance III	3.6 Qtr. Credits
MATH 512	Partial Differential Equations	3 Sem. Credits
MATH 513	PDE's for Finance	3 Sem. Credits
MATH 543	Stochastic Analysis	3 Sem. Credits
MATH 544	Stochastic Dynamics	3 Sem. Credits
MATH 583	Quantative Modeling of Derivative	3 Sem. Credits
MATH 589	Numerical Methods for PDEs	3 Sem. Credits
CS 522	Data Mining	3 Sem. Credits

Minimum Total for Elective Courses 10.8 Quarter Credits and 6 Semester Credits

Total Minimum Credits 21.6 Quarter Credits and 18 Semester Credits

A student can transfer a maximum of 2 graduate courses from other institutions in equivalent courses.

Note: 3.6 Quarter Credits is equivalent to 2.4 Semester Credits.

Master of Science in Applied Mathematics

32 credit hours
Thesis
Comprehensive exam (Certification)

The M.S. degree program provides a broad background in the fundamentals of the advanced mathematics that is applied to solve problems in the other fields. The goal is to prepare students for careers in industry and for the doctoral program.

Required courses

A Master's thesis (up to 5 credit hours of MATH 594), under the supervision of a faculty member, and at least two of the basic sequences in the four core areas of study:

Applied Analysis

MATH 500 Applied Analysis I
MATH 501 Applied Analysis II

Discrete Applied Mathematics

MATH 553 Discrete Applied Mathematics I
MATH 554 Discrete Applied Mathematics II

Computational Mathematics

MATH 577 Computational Mathematics I
MATH 578 Computational Mathematics II

Stochastics

MATH 543 Stochastic Analysis
MATH 544 Stochastic Dynamics

Elective courses

The remaining courses in each student's program are selected in consultation with, and approval of, the Director of Graduate Studies. The program may include at most three courses at the 400-level and at most two courses outside the department.

The comprehensive examination requirement is fulfilled by achieving certification in two of the core areas of study. For procedures governing the certification process, the student should consult the current department regulations.

Doctor of Philosophy in Applied Mathematics

84 credit hours beyond the bachelor's degree
Qualifying exam
Comprehensive exam
Dissertation and Defence

The Ph.D. program provides advanced education through coursework (including independent study) and original, creative research in order to prepare students for careers in industrial research and academia. The program requires a total of 84 credit hours (approximately 52 for students entering with a master's degree).

The qualifying examination requirement is fulfilled by achieving better than a 3.5/4.0 GPA on the courses taken in three of the core areas of study listed under the M.S. degree and passing an oral examination within the first five semesters of study (within the first three semesters for students entering with a master's degree). The exam covers three of the four core areas, which can be chosen by the student. The comprehensive examination consists of an oral examination based on the student's research proposal. The exam aims to ensure that the student has the background to carry out successful research in his/her chosen area and the proposed research has sufficient scholarly merit. Exceptions to these general rules require approval by the departmental Graduate Studies Committee.

Besides the courses in the core areas of study, the remaining courses in the program are selected in consultation with the student's academic adviser. The program must include at least three (but no more than five) courses in an area of concentration outside of the department, as approved by the director of graduate studies; these may include 400-level courses.

The dissertation (thesis) is expected to contain a distinct and substantial, original and publishable contribution to the field of study. The credit hours devoted to thesis research (MATH 691) must total between 24 and 32. An oral examination in defense of the thesis constitutes completion of the degree.

Course Descriptions

Numberes in parentheses represent class, lab and total credit hours, respectively.

MATH 400
Real Analysis
Real numbers, continuous functions; differentiation and Riemann integration. Functions defined by series. Prerequisite: MATH 251 or instructor's consent. (3-0-3)

MATH 401
Analysis II
Functions of several variables, partial differentiation, and multiple integrals. Prerequisite: MATH400. (3-0-3)

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

MATH 405
Introduction to Iteration and Chaos
Functional iteration and orbits, periodic points and Sharkovsky's cycle theorem, chaos and dynamical systems of dimensions one and two. Julia sets and fractals, physical implications. Prerequisites: MATH 251, MATH 252 and one of the following: MATH 332, MATH 333 or instructor's consent. (3-0-3) (C)

MATH 410
Number Theory
Divisibility, congruences, distribution of prime numbers, Diophantine equations, applications to encryption methods. Prerequisite: MATH 230 or instructor's consent. (3-0-3)

Math 420
Geometry
The course is focused on selected topics related to fundamental concepts and methods of Euclidean geometry in two and three dimensions and their applications with emphasis on various problem-solving strategies, geometric proof, visualization, and interrelation of different areas of mathematics. Prerequisites: consent of the instructor. (3-0-3)

MATH 426
Statistical Tools For Engineers
Descriptive statistics and graphs, probability distributions, random sampling, independence, significance tests, design of experiments, regression, time-series analysis, statistical process control, and introduction to multivariate analysis. Prerequisite: Junior standing. Same as CHE 426. (Credit not given for both MATH 426 and CHE 426. (3-0-3)

Math 430
Applied Algebra
Relations; modular arithmetic; group theory: symmetry, permutation, cyclic, and abelian groups; group structure: subgroups, cosets, homomorphisms, classification theorems; rings and fields. Applications to crystallography, cryptography, and check-digit schemes. Prerequisite: MATH 230 or MATH 332. (3-0-3)

MATH 453
Combinatorics
Permutations and combinations; pigeonhole principle; inclusion-exclusion principle; recurrence equations and generating functions; enumeration under group action. Prerequisite: MATH 230. (3-0-3)

MATH 454
Graph Theory and Applications
Graph theory is the study of systems of points with some of the pairs of points joined by lines. Sample topics include: paths, cycles and trees; adjacency and connectivity; directed graphs; Hamiltonian and Eulerian graphs and digraphs; intersection graphs. Applications to the sciences (computer, life, physical, social) and engineering will be introduced throughout the course. Credit will not be granted for both MATH 454 and MATH 553. Prerequisite: MATH 230, MATH 251 or MATH 252. (3-0-3)

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

MATH 471
Numerical Methods
Number representation, errors, iterative methods for nonlinear equations, polynomial interpolation, differentiation, integration, Gauss elimination. Prerequisites: MATH 251, MATH 252. Corequisite: MATH 332 or MATH 333. (3-0-3)

MATH 474
Probability and Statistics
Elementary probability theory including discrete and continuous distributions; sampling, estimation, confidence intervals, hypothesis testing, and linear regression. Prerequisite: MATH 251. Credit not granted for both MATH 474 and MATH 475. (3-0-3)

MATH 475
Probability
Elementary probability theory; combinatorics; random variables; discrete and continuous distributions; joint distributions and moments; transformations and convolution; basic theorems; simulation. Prerequisite: MATH 251. Credit not granted for both MATH 474 and MATH 475. (3-0-3)

MATH 476
Statistics
Estimation theory; hypothesis tests; confidence intervals; goodness-offit tests; correlation and linear regression; analysis of variance; nonparametric methods. Prerequisite: MATH 475. (3-0-3)

MATH 477
Numerical Linear Algebra
Fundamentals of matrix theory, least squares problems, computer arithmetic, conditioning and stability, direct and iterative methods for linear systems, eigenvalue problems

Credit may not be granted for both MATH 477 and MATH 473.. Prerequisite: MATH 471 or consent of the instructor. (3-0-3)

MATH 478
Numerical Methods for Differential Equations
Polynomial interpolation; numerical integration; numerical solution of initial value problems for ordinary differential equations by single and multi-step methods, Runge-Kutta, Predictor-Corrector; numerical solution of boundary value problems for ordinary differential equations by shooting method, finite differences. Credit may not be granted for both MATH 478 and MATH 472. Prerequisite: MATH 471 or consent of instructor. (3-0-3)

MATH 481
Introduction to Stochastic Processes
This is an introductory course in stochastic processes. Its purpose is to introduce students into a range of stochastic processes, which are used as modeling tools in diverse fields of applications, especially in the business applications. The course introduces the most fundamental ideas in the area of modeling and analysis of real World phenomena in terms of stochastic processes. The course covers different classes of Markov processes. It also presents some aspects of stochastic calculus with emphasis on the application to financial modeling and financial engineering. Prerequisite: MATH 332 or MATH 333, MATH 475. (3-0-3)

MATH 482
Introduction to Markov Processes
Random walks, discrete time Markov chains; Poisson processes, continuous time Markov chains; renewal theory. Prerequisite: MATH 475. (3-0-3)

MATH 483
Design and Analysis of Experiments
Principles of estimation; hypothesis tests, confidence intervals. Contingency tables; goodness-of-fit. Analysis of variance; linear regression. Hierarchical and split plot designs; analysis of covariance. Multiple regression. Prerequisites: MATH 476. (3-0-3)

MATH 485
Introduction to Mathematical Finance
This is an introductory course in mathematical finance. Technical difficulty of the subject is kept at a minimum by considering a discrete time framework. Nevertheless, the major ideas and concepts underlying modern mathematical finance and financial engineering will be explained and illustrated. Prerequisite: MATH475 or equivalent.(3-0-3)

MATH 486
Mathematical Modeling I
A general introduction to optimization problems. Linear programming: the simplex method. Elements of graphs and networks. Introduction to game theory. Applications. Prerequisite: MATH 475 or instructor's consent. (3-0-3) (C)

MATH 487
Mathematical Modeling II
The formulation of mathematical models, solution of mathematical equations, interpretation of results. Selected topics from queueing theory and financial derivatives. Prerequisite: MATH 252. (3-0-3) (C)

MATH 488
Ordinary Differential Equations and Dynamical Systems
Boundary-value problems: Green's functions, Sturm-Liouville theory, eigenfunction expansions. Linear and nonlinear systems: existence and uniqueness, Floquet theory, stability concepts. Phase-plane analysis; critical points, limit cycles. Prerequisites: MATH 252. (3-0-3)

MATH 489
Partial Differential Equations
First-order equations, characteristics. Classification of second-order equations. Laplace's equation; potential theory. Green's functions, maximum principles. The wave equation: characteristics, general solution. The heat equation: Use of integral transforms. Prerequisite: MATH 461. (3-0-3)

MATH 491
Reading and Research
(Credit: Variable)

Math 500
Applied Analysis I
Metric and Normed Spaces; Continuous Functions; Contraction Mapping Theorem; Topological Spaces; Banach Spaces; Hilbert Spaces; Eigenfunction expansion. Prerequisites: MATH 400 or consent of the instructor. (3-0-3)

Math 501
Applied Analysis II
Bounded Linear Operators on a Hilbert Space; Spectrum of Bounded Linear Operators; Linear Differential Operators and Green's Functions; Distributions and the Fourier Transform; Measure Theory, Lebesgue Integral and Function Spaces; Differential Calculus and Variational Methods. Prerequisites: MATH 500 or consent of the instructor. (3-0-3)

Math 512
Partial Differential Equations
Basic model equations describing wave propagation, diffusion and potential functions; characteristics, Fourier transform, Green function, and eigenfunction expansions; elementary theory of partial differential equations; Sobolev spaces; linear elliptic equations; energy methods; semigroup methods; applications to partial differential equations from engineering and science. Prerequisites: MATH 461 or MATH489 or consent of the instructor. (3-0-3)

Math 515
Ordinary Differential Equations and Dynamical Systems
Basic theory of systems of ordinary differential equations; equilibrium solutions, linearization and stability; phase portraits analysis; stable, unstable and center manifolds; periodic orbits, homoclinic and heteroclinic orbits; bifurcations and chaos; nonautonomous dynamics; and numerical simulation of nonlinear dynamics. Prerequisites: MATH 252 or consent of the instructor. (3-0-3)

MATH 519
Complex Analysis
Analytic functions, contour integration, singularities, series, conformal mapping, analytic continuation, multivalued functions. Prerequisite: MATH 402 or instructor's consent. (3-0-3)

MATH 530
Algebra
Axiomatic treatment of groups, rings and fields, ideals and homomorphisms; field extensions, modules over rings. Prerequisite: MATH 332 or MATH 430. (3-0-3)

Math 532
Linear Algebra
Matrix algebra, vector spaces, norms, inner products and orthogonality, determinants, linear transformations, eigenvalues and eigenvectors, Cayley-Hamilton theorem, matrix factorizations (LU, QR, SVD). Prerequisites: MATH 332 or consent of the instructor. (3-0-3)

MATH 540
Probability
Random events and variables, probability distributions, sequences of random variables and limit theorems. Prerequisite: MATH 400 or instructor's consent. (3-0-3)

MATH 542
Stochastic Processes
This is an introductory course in stochastic processes. Its purpose is to introduce students to a range of stochastic processes, which are used as modeling tools in diverse fields of applications, especially in the business applications. The course introduces the most fundamental ideas in the area of modeling and analysis of real world phenomena in terms of stochastic processes. The course covers different classes of Markov processes: discrete and continuous-time Markov chains, Brownian motion and diffusion processes. It also presents some aspects of stochastic calculus with emphasis on the application to financial modeling and finanacial engineering. Credits cannot be given to both Math 481 and Math 542. Prerequisite: MATH332 or MATH333 and MATH475. (3-0-3)

Math 543
Stochastic Analysis
This course will introduce the student to modern finite dimensional stochastic analysis and its applications. The topics will include: a) an overview of modern theory of stochastic processes, with focus on semimartingales and their characteristics, b) stochastic calculus for semimartingales, including Ito formula and stochastic integration with respect to semimartingales, c) stochastic differential equations (SDE's) driven by semimartingales, with focus on stochastic SDE's driven by Levy processes, d) absolutely continuous changes of measures for semimartingales, e) some selected applications. Prerequisite: MATH 475 or consent of an instructor. (3-0-3)

MATH 544
Stochastic Dynamics
This course is about modeling, analysis, simulation and prediction of dynamical behavior of complex systems under random influences. The mathematical models for such systems are in the form of stochastic differential equations. It is especially appropriate for graduate students who would like to use stochastic methods in their research, or to learn these methods for long term career development. Topics include white noise and colored noise, stochastic differential equations, random dynamical systems, numerical simulation, and applications to scientific, engineering and other areas. Prerequisite:MATH 474, MATH 475 or MATH 543 or equivalent.

MATH 545
Stochastic Partial Differential Equations
This course introduces various methods for understanding solutions and dynamical behaviors of stochastic partial differential equations arising from mathematical modeling in science and engineering and other areas. It is designed for graduate students who would like to use stochastic methods in their research or to learn such methods for long term career development. Topics include: Random variables, Brownian motion and stochastic calculus in Hilbert spaces; Stochastic heat equation; Stochastic wave equation; Analytical and approximation techniques; Stochastic numerical simulations via Matlab; Dynamical impact of noises; Stochastic flows and cocycles; Invariant measures, Lyapunov exponents and ergodicity; and applications to engineering and science and other areas.Prerequisites: MATH 543 or MATH 544 or consent of instructor. (3-0-3)

MATH 546
Introduction to Time Series
Properties of stationary, random processes; standard discrete parameter models, autoregressive, moving average, harmonic; standard continuous parameter models. Spectral analysis of stationary processes, relationship between the spectral density function and the autocorrelation function; spectral representation of some stationary processes; linear transformations and filters. Introduction to estimation in the time and frequency domains. Prerequisite: MATH 475 or ECE 511. (3-0-3)

Math 548
Mathematical Finance I: Discrete Time
This is an introductory course in mathematical finance. Technical difficulty of the subject is kept at a minimum by considering a discrete time framework. Nevertheless, the major ideas and concepts underlying modern mathematical finance and financial engineering will be explained and illustrated. Credits cannot be given to both Math 485 and Math 548. Prerequisite: MATH474 or MATH475 and MATH481 or MATH542. (3-0-3)

MATH 550
Topology
Topological spaces, continuous mappings and homoeomorphisms, metric spaces and metrizability, connectedness and compactness, homotopy theory. Prerequisite: MATH 556. (3-0-3)

MATH 553
Discrete Applied Mathematics I
Graph theory is the study of systems of points with some of the pairs of points joined by lines. Sample topics include: paths, cycles and trees; adjacency and connectivity; directed graphs; Hamiltonian and Eulerian graphs and digraphs; intersection graphs. Applications to the sciences (computer, life, physical, social) and engineering will be introduced throughout the course. This course runs concurrently with Math 454 but projects and homework are at the graduate level. Credits cannot be given to both MATH 553 and MATH 454. Prerequisite: Math 453 or instructor's consent. (3-0-3)

Math 554
Discrete Applied Mathematics II
Graduate level treatment of applied combinatorics; posets: product and dimension, lattices, extremal set theory and symmetric chain decomposition; combinatorial designs: block designs, Latin Squares, finite fields, block designs and Steiner systems, finite projective planes; coding theory: error-correcting codes, Hamming and sphere bounds, linear codes, codes from liar games and adaptive coding. Prerequisite: MATH 453, MATH 454, or MATH 553. (3-0-3)

MATH 555
Tensor Analysis
Development of the calculus of tensors with applications to differential geometry and the formulation of the fundamental equations in various fields. Prerequisites: MATH 332 and either MATH 400 or instructor's consent. (3-0-3)

MATH 556
Metric Spaces
Point-set theory, compactness, completeness, connectedness, total boundedness, density, category, uniform continuity and convergence, Stone-Weierstrass theorem, fixed-point theorems.
Prerequisite: MATH 400. (3-0-3)

Math 557
Probabilistic Methods in Combinatorics
Graduate level introduction to probabilistic methods, including linearity of expectation, the deletion method, the second moment method and the Lovász Local Lemma. Many examples from classical results and recent research in combinatorics and graph theory will be included throughout, including from Ramsey Theory, random graphs, coding theory, and number theory. Prerequisite: graduate status or consent of instructor. (3-0-3)

MATH 563
Statistics
Theory of limiting distributions; interval and point estimation, sufficient statistics. Bayesian procedures, hypothesis testing, nonparametric methods. Prerequisite: MATH 475. (3-0-3)

MATH 564
Applied Statistics
Linear regression and correlation models, regression parameters, prediction and confidence intervals, time series, analysis of variance and covariance. Prerequisites: MATH 332 and MATH 475, or instructor's consent. (3-0-3)

Math 565
Monte Carlo Methods in Finance
In addition to the theoretical constructs in financial mathematics, there are also a range of computational/simulation techniques that allow for the numerical evaluation of a wide range of financial securities. This course will introduce the student to some such simulation techniques, known as Monte Carlo methods, with focus on applications in financial risk management. Monte Carlo and Quasi Monte Carlo techniques are computational sampling methods which track the behavior of the underlying securities in an option or portfolio and determine the derivative's value by taking the expected value of the discounted payoffs at maturity. Recent developments with parallel programming techniques and computer clusters have made these methods widespread in the finance industry. Prerequisite: MATH474. (3-0-3)

MATH 566
Multivariate Analysis
Random vectors, sample geometry and random sampling, generalized variance, multivariate normal and Wishart distributions, estimation of mean vector, confidence region, Hotelling's T2, covariance, principal components, factor analysis, discrimination, clustering. Prerequisites: MATH 532, MATH 563, MATH 564. (3-0-3)

MATH 567
Design and Analysis of Experiments
Analysis of variance, fixed, random, and mixed effects models, analysis of covariance, randomized designs, randomized blocks, nested designs, Latin square and related designs. Prerequisite: MATH 476. (3-0-3)

MATH 568
Topics in Statistics
Categorical data analysis, contingency tables, log-linear models, nonparametric methods, sampling techniques. Prerequisite: MATH 563. (3-0-3)

MATH 577
Computational Mathematics I
Fundamentals of matrix theory, least squares problems, computer arithmetic, conditioning and stability, direct and iterative methods for linear systems, eigenvalue problems. Credits cannot be given to both Math477 and Math577. Prerequisite: MATH 471 or instructor's consent. (3-0-3)

Math 578
Computational Mathematics II
Polynomial interpolation; numerical integration; numerical solution of ordinary differential equations by single and multi-step methods, Runge-Kutta, Predictor-Corrector; numerical solution of boundary value problems for ordinary differential equations by shooting methods, finite

differences and spectral methods. Credits cannot be granted for both MATH 578 and MATH 478. Prerequisite: MATH 471 or instructor's consent. (3-0-3)

Math 579
Complexity of Numerical Problems
This course is concerned with a branch of complexity theory. It studies the intrinsic complexity of numerical problems, that is, the minimum effort required for the approximate solution of a given problem up to a given error. Based on a precise theoretical foundation, lower bounds are established, i.e. bounds that hold for all algorithms. We also study the optimality of known algorithms, and describe ways to develop new algorithms if the known ones are not optimal. Prerequisite: MATH471. (3-0-3)

MATH 581
Theory of Finite Elements
The geometry of the various elements, the element matrices, assembly of stiffness matrices, analysis of error estimates and convergence proofs. Applications. Prerequisite: MATH 400 or instructor's consent. (3-0-3)

Math 582
Mathematical Finance II: Continuous Time
This course is a continuation of Math 485/548. It introduces the student to modern continuous time mathematical finance. The major objective of the course is to present main mathematical methodologies and models underlying the area of financial engineering, and, in particular, those that provide a formal analytical basis for valuation and hedging of financial securities. Prerequisite: MATH 485/548; MATH 481/542, or consent of an instructor. (3-0-3)

Math 586
Theory and Practice of Fixed Income Modeling
The course covers basics of the modern interest rate modeling and fixed income asset pricing. The main goal is to develop a practical understanding of the core methods and approaches used in practice to model interest rates and to price and hedge interest rate contingent securities. The emphasis of the course is practical rather than purely theoretical. A fundamental objective of the course is to enable the students to gain a hand-on familiarity with and understanding of the modern approaches used in practice to model interest rate markets. Prerequisite: MATH543 and MATH485 or consent of the instructor. Corequisite: MATH582. (3-0-3)

Math 589
Numerical Methods for Partial Differential Equations
Introduction to numerical methods especially finite difference methods for solving partial differential equations including parabolic, hyperbolic and elliptic equations. Topics include convergence, stability, iterative methods for elliptic problems, various finite difference methods for parabolic, hyperbolic PDEs and Navier-Stokes equations and their properties, introduction to finite volume method and finite element method. Prerequisites: Math 471 and Math 489 or instructor consent. (3-0-3)

Math 591
Research and Thesis for M.S. Degree
(Credit: variable)

MATH 593
Seminar in Mathematics
(Credit: Variable)

MATH 594
Special Projects
(Credit: Variable)

MATH 596
Math For Teachers: Elementary
An in-service workshop for precollege teachers emphasizing the phenomenological approach to the teaching of mathematics. Prerequisite: Certification as mathematics teacher or approval of the instructor. (Credit: Variable)

MATH 597
Reading and Special Projects
(Credit: Variable)

MATH 598
Math For Teachers: High School
An in-service workshop for precollege teachers emphasizing the phenomenonological approach to teaching of integrated mathematics and science at the high school level. Prerequisite: Certification as teacher or approval of instructor. (Credit: Variable)

MATH 601
Advanced Topics in Combinatorics
Course content is variable and reflects current research in combinatorics. Prerequisite: MATH 554 or instructor's consent. (3-0-3)

MATH 602
Advanced Topics in Graph Theory
Course content is variable and reflects current research in graph theory. Prerequisite: MATH 554 or instructor's consent. (3-0-3)

MATH 603
Advanced Topics in Computational Mathematics
Course content is variable and reflects current research in computational mathematics. Prerequisite: MATH 578 or instructor's consent. (3-0-3)

MATH 604
Advanced Topics in Applied Analysis
Course content is variable and reflects current research in applied analysis. Prerequisite: MATH 501 or instructor's consent. (3-0-3)

MATH 605
Advanced Topics in Stochastic Analysis
Course content is variable and reflects current research in stochastic analysis. Prerequisite: MATH 564 or instructor's consent. (3-0-3)

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