Applied Mathematics and Statistics (AMS)

Chair: James Glimm, Mathematics Building P-137, (631) 632-8355
Graduate Program Director: Xiaolin Li, Mathematics Building 1-121, (631) 632-8354
Graduate Secretary: Christine Rota, Mathematics Building 1-122, (631) 632-8360

Advanced Graduate Certificate awarded: Advanced Graduate Certificate in Operations Research
Degrees awarded: M.S. in Applied Mathematics and Statistics; Ph.D. in Applied Mathematics and Statistics

The Department of Applied Mathematics and Statistics, within the College of Engineering and Applied Sciences, offers programs in computational applied mathematics, computational biology, operations research, and statistics, leading to the M.S. and Ph.D. degrees. The Department offers an integrated series of courses and seminars, supervised reading, and facilities for research. Emphasis is on the study of real-world problems, computational modeling, and the development of necessary analytical concepts and theoretical tools. A state-of-the-art, computational laboratory is operated for student education and research. A University-based, 100Tf, BlueGene super computer and an xx node linux cluster are available for student access. This laboratory includes an advanced parallel supercomputer that is one of the most powerful machines of its type on the East Coast. It also features a network of advanced Unix workstations and modern printing facilities. The laboratory's full-time staff is available to help students become familiar with the laboratory facilities.

Students participate in joint research with five national laboratories, several industrial groups, and various science, biomedical, and engineering programs. Students, who receive a broad training, find themselves excellently prepared for careers in government and industry in which mathematics is used as a computational or conceptual tool.

Faculty research programs receive significant external funding and provide students with an opportunity for active participation in a variety of projects in all areas of the Department. Faculty interests include applied graph theory, biostatistics, combinatorial optimizations, computational biology, computational fluid dynamics, computational statistics, data analysis, flow through porous media, fracture mechanics, inverse problems, mixed-boundary value problems, nonlinear conservation laws, nonparametric statistics, reliability theory, robust estimation, sequential decision making and control theory, stochastic modeling, and structure-based drug design. Most doctoral students are supported through either a research or teaching assistantship.

The Ph.D. program normally takes about four to five years for students with a strong analytical and computing background. The M.S. programs, when pursued on a full-time basis, may be completed in three or four semesters. Students who have taken graduate courses before enrolling at Stony Brook may request transfer of credit (limited to six credits). If such a request is approved, it may be possible to complete the M.S. degree in two semesters. It is strongly urged that all applicants develop some facility in computer programming.

A more detailed description of the graduate program is available from the Departmental office. This includes specific distribution requirements, fields of specialization, and information on the preliminary and qualifying examinations. Interested students should request information and application forms as early as possible, especially if they plan to apply for financial aid.

Admission

For admission to graduate study, the minimum requirements are as follows:

A. A bachelor's degree in chemistry, engineering, mathematics, physics, or the social sciences with a strong mathematics background;

B. A minimum grade point average of at least 3.00 in all courses in pertinent or related fields;

C. Results of the Graduate Record Examination (GRE) General Test;

D. Three letters of reference and all transcripts of undergraduate study completed;

E. Acceptance by both the Department of Applied Mathematics and Statistics and the Graduate School;

F. Students admitted provisionally must satisfy designated course and grade point average requirements during the first year of graduate study before being admitted to full degree candidacy.

Advanced Graduate Certificate Program in Operations Research

This advanced certificate program of 18 credits, consisting of six three-credit courses, trains students in the fundamental mathematical tools for working in the operations research profession. Operations research is the field of applied mathematics related to efficient management of the activities of government agencies, nonprofit organizations, and private companies. The following courses are required for the certificate:

1. AMS 507 Introduction to Probability
2. AMS 540 Linear Programming
3. AMS 550 Stochastic Models
4. AMS 553 Simulation and Modeling
5. AMS 572 Statistical Methods for Social Scientists
6. Elective chosen by student in consultation with advisor

Combined B.S./M.S. Degree

Undergraduate applied mathematics majors with strong academic credentials (minimum of 3.00 in the Applied Mathematics major) may apply for admission to the special Bachelor of Science-Master of Science program in Applied Mathematics and Statistics at the end of the junior year. The combined B.S./M.S. program in Applied Mathematics and Statistics allows students with superior academic records to use up to nine graduate credits toward the B.S. and M.S. requirements. In essence, those nine credits count toward two goals simultaneously. Normally, it would take six years to complete two separate degrees. With the combined B.S./M.S. program, there is only a five-year commitment (10 semesters). The advantage of the combined program is that the M.S. degree can be earned in less time, thus costing less money, than required by the traditional course of study.

In the first semester of the senior year, students in the B.S./M.S. program may take up to six graduate credits. In the second semester of the senior year, they become enrolled as graduate students, and continue on as graduate students during the fifth year. Because students in this program only need to earn 111 undergraduate credits, they are usually finished with undergraduate coursework by the first semester of their senior year. If needed, they may continue to take some undergraduate courses after they become graduate students.

When the student is accepted, permission will be granted to take six graduate credits that will be applied toward the master's degree. The requirements for the B.S. degree must be completed before admission to the graduate program. At least 24 additional credits including the requirements stated in the Graduate Bulletin must be earned to qualify the student for the master's degree. Further information about the combined program may be obtained from either the graduate program director or the undergraduate program.

Part-Time Graduate Studies

In addition to the full-time graduate program leading to the M.S. and Ph.D. degrees with specializations in computational applied mathematics, operations research, and statistics, the Department conducts a part-time program on campus. The part-time program is governed by regulations governing the resident full-time program with the exception that students in the part-time program have greater flexibility in choosing the time for the qualifying examination if they are contemplating pursuing the Ph.D.

The purpose of the part-time program is to provide an opportunity for men and women who are employed full time to pursue graduate study leading to advanced degrees in applied mathematics, operations research, and statistics. Applicants who hold a bachelor's degree in applied mathematics, engineering, mathematics, life sciences, physical sciences, or social sciences with a strong background in undergraduate mathematics, will be considered for admission to this program. Qualified students may continue beyond the master's degree for the Ph.D. degree.

Additional information may be obtained from the graduate program director at the Department of Applied Mathematics and Statistics, Stony Brook University, Stony Brook, NY 11794-3600.

Faculty

Distinguished Professors

Glimm, James, *Chair,* Ph.D., 1959, Columbia University: Nonlinear equations, conservation laws; computational fluid dynamics; mathematical physics.

Distinguished Teaching Professors

Tanur, Judith, Ph.D., 1972, Stony Brook University: Application of statistics in social sciences; survey methodology.

Tucker, Alan, Ph.D., 1969, Stanford University: Graph theory; combinatorial algorithms.

Professors

Ahn, Hongshik, Ph.D., 1992, University of Wisconsin, Madison: Biostatistics; tree-structured regression.

Arkin, Esther, Ph.D., 1986, Stanford University: Combinatorial optimization; network flows; computational geometry.

Beltrami, Edward J., *Emeritus*, Ph.D., 1962, Adelphi University: Optimization techniques; models for public systems analysis.

Chen, Yung Ming, *Emeritus*, Ph.D., 1963, New York University: Numerical analysis and methods; numerical methods for solving inverse problems; large-scale numerical simulations.

Deng, Yuefan, Ph.D., 1989, Columbia University: Molecular dynamics; parallel computing.

Dicker, Daniel, *Emeritus*, D.Eng.Sc., 1961, Columbia University: Boundary value problems of solids and fluids; aeroelastic analysis of suspension bridges.

Feinberg, Eugene, Ph.D., 1979, Vilnius State University, Lithuania: Probability theory and statistics; control theory and applications in communication systems; transportation; computer networks and manufacturing.

Finch, Stephen, Ph.D., 1974, Princeton University: Robust estimation and nonparametric statistics.

Li, Xiaolin, Ph.D., 1987, Columbia University: Computational fluid dynamics; numerical analysis.

Lindquist, Brent, Ph.D., 1981, Cornell University: Flow in porous media; computational fluid dynamics.

Mendell, Nancy, Ph.D., 1972, University of North Carolina at Chapel Hill: Biostatistics.

Mitchell, Joseph, Ph.D., 1986, Stanford University: Operations research; computational geometry; combinatorial optimization.

Reinitz, John, Ph.D., 1988, Yale University: Theory of fundamental biological processes; bioinformatics; optimization; developmental biology and gene regulation .

Srivastav, Ram P., *Emeritus*, Ph.D., 1958, Lucknow University, India; Ph.D., 1963, D.Sc., 1972, Glasgow University, Scotland: Fracture mechanics; integral equations; mixed boundary value problems.

Tewarson, Reginald P., *Emeritus*, Ph.D., 1961, Boston University: Numerical analysis and computational methods; sparse matrices; generalized inverses and large nonlinear systems; mathematical models of diffusion problems in biology and medicine.

Zhu, Wei, Ph.D., 1996, University of California, Los Angeles: Biostatistics; optimal experimental design; linear models; structural equation modeling.

Associate Professors

Samulyak, Roman, Ph.D, 1999, New Jersey Institute of Technology: Mathematical physics, computational applied mathematics.

Assistant Professors

Green, David, Ph.D., 2002, MIT: Computational biology; protein structure.

Hu, Jiaqiao, Ph.D., 2006, University of Maryland: Stochastic optimization, dynamic programming.

Jiao, Xiangmin, Ph.D., 2001, University of Illinois: Numerical analysis, computational geometry.

Rizzo, Robert, Ph.D., 2001, Yale University: Computational biology; structure-based drug design.

Xing, Haipeng, Ph.D., 2005, Stanford University: Financial econometrics; time series modeling.

Research Professor

Frey, Robert, Ph.D., 1986, Stony Brook University: Quantitative finance.

Research Assistant Professor

Yu, Yan, Ph.D., 2005, Stony Brook University: Numerical analysis and computational fluid dynamics.

Adjunct Faculty

Badr, Hussein G.,[1] *Associate Professor*, Ph.D., 1980, Pennsylvania State University: Operating systems; computer system performance evaluation.

Bender, Michael,[1] *Associate Professor*, Ph.D., 1996, Harvard University: Combinatorial algorithms.

Dubey, Pradeep,[2] *Professor*, Ph.D., 1975, Cornell University: Game theory; mathematical economics.

Ferguson, David,[3] *Professor,* Ph.D., 1980, University of California, Berkeley: Mathematics education; educational technology.

Grove, John,[4] *Professor,* Ph.D., 1984, Ohio State University: Conservation laws; front tracking.

Pinezich, John,[5] *Professor*, Ph.D., 1998, Stony Brook University: Radar; ballistics; sonar; acoustics.

Sharp, David,[4] *Professor,* Ph.D., 1963, California Institute of Technology: Mathematical physics; computational fluid dynamics.

Simmerling, Carlos,[6] *Associate Professor*, Ph.D., 1995, University of Illinois at Chicago: Protein structure.

Skiena, Steven,[1] *Professor*, Ph.D., 1988, University of Illinois: Combinatorial algorithms; computational geometry; data structures.

Skorin-Kapov, Jadranka,[7] *Professor*, Ph.D., 1988, University of British Columbia, Canada: Mathematical programming; production management.

Sokal, Robert R.,[8] *Emeritus Distinguished Professor*, Ph.D., 1952, University of Chicago: Numerical taxonomy; theory of systematics; geographic variation; spatial models in ecology and evolution.

Spirov, Alexander, *Associate Professor*, Ph.D., 1987, Irktsk State University: Computational biology.

Wang, Jin,[6] *Assistant Professor*, Ph.D., 1991, University of Illinois: Biomolecular folding and recognition: protein–protein interactions.

Weinig, Sheldon, *Professor*, Ph.D., 1955, Columbia University: Manufacturing management; material sciences.

Zemanian, Armen H.,[9] *Distinguished Professor*, Eng.Sc.D., 1953, New York University: Network theory; food system modeling.

Number of teaching, graduate, and research assistants, Fall 2007: 75

1) Department of Computer Science

2) Department of Economics

3) Department of Technology and Society

4) Los Alamos National Laboratory

5) Advanced Accoustical Concepts

6) Department of Chemistry

7) W. Averell Harriman School for Management and Policy

8) Depratment of Ecology and Evolution

9) Department of Electrical and Computer Engineering

Degree Requirements

Requirements for the M.S. Degree

In addition to the minimum Graduate School requirements, the following are required:

A. Course Requirements

The M.S. degree in the Department of Applied Mathematics and Statistics requires the satisfactory completion of a minimum of 30 graduate credits in letter-graded (A, B, C, F) graduate courses.

All credits in satisfaction of the degree must be at the graduate level. The Department may impose additional requirements as described below. In addition, the average for all courses taken must be B or higher, and at least 18 credits of all courses taken must carry a grade of B or higher.

The student pursues a program of study planned in consultation with an academic advisor. The program and any subsequent modifications require approval by the graduate program director.

Core Requirements for the M.S. Degree

1. Applied Mathematics

AMS 501 Differential Equations and Boundary Value Problems
AMS 503 Applications of Complex Analysis
AMS 504 Foundations of Applied Mathematics
AMS 505 Applied Linear Algebra
AMS 526 Numerical Analysis I
AMS 527 Numerical Analysis II
AMS 595 Fundamentals of Computing

2. Computational Biology

AMS 507 Probability
AMS 510 Analytical Methods for Applied Mathematics and Statistics
MCB 520 Graduate Biochemistry OR
CHE 541 Biomolecular Structure and Analysis
AMS 530 Principles in Parallel Computing
AMS 532 Laboratory Rotations and Journal Club in Computational Biology
AMS 533 Numerical Methods and Algorithms in Computational Biology
AMS 535 Intro to Computational Structural Biology and Drug Design
CSE 549 Computational Biology

3. Operations Research

AMS 510 Analytical Methods for Applied Mathematics and Statistics
AMS 507 Introduction to Probability
AMS 540 Linear Programming
AMS 550 Stochastic Models
AMS 556 Dynamic Programming or
AMS 553/CSE 529 Simulation and Modeling or
AMS 542/CSE 548 Analysis of Algorithms
One course in statistics
AMS 595 Fundamentals of Computing

4. Statistics

AMS 510 Analytical Methods for Applied Mathematics and Statistics or
AMS 504 Foundations of Applied Mathematics and
AMS 505 Applied Linear Algebra
AMS 507 Introduction to Probability
AMS 570 Mathematical Statistics I
AMS 572 Exploratory Data Analysis
AMS 575 Internship in Statistical Consulting
AMS 578 Regression Theory
AMS 582 Design of Experiments
AMS 595 Fundamentals of Computing

Elective Requirements for the M.S. Degree

Any graduate-level AMS or other graduate-level courses in a related discipline approved by the graduate program director may be used to satisfy the credit requirement beyond the core course requirement.

B. Final Recommendation

Upon fulfillment of the above requirements, the faculty of the graduate program will recommend to the Dean of the Graduate School that the M.S. degree be conferred or will stipulate further requirements that the student must fulfill.

C. Time Limit

All requirements for the M.S. degree must be completed within three years of the student's first registration as a full-time graduate student.

Requirements for the Ph.D. Degree

A. Course Requirements

The course of study prescribed for the M.S. degree provides basic guidelines for doctoral study. The student pursues a program of study planned in consultation with an academic advisor. The program and any subsequent modifications require approval of the graduate program director.

B. Qualifying Examination

A student must pass a qualifying examination to be allowed to continue toward the Ph.D. degree. The qualifying examination is given twice a year at the beginning and end of the spring semester and is designed to test the student's preparation to do research in Applied Mathematics. Each student must demonstrate competency in algebra and analysis and in-depth knowledge in one of the following areas:

Computational Applied Mathematics

Computational Biology

Operations Research

Statistics

C. Research Advisor

After completion of at least one year of full-time residence and prior to taking the preliminary examination, the student must select a research advisor who agrees to serve in that capacity.

D. Preliminary Examination

This is an oral examination administered by a committee and given to the student when he or she has developed a research plan for the dissertation. The plan should be acceptable to the student's research advisor.

E. Mathematical Writing Requirement

The mathematical writing requirement is associated with the preliminary oral examination. The student must submit a document, typically 20 to 25 double-spaced pages long, containing the literature search synopsis for the proposed dissertation as well as research work accomplished to date. It must be given to the members of the preliminary examination committee at least one week before the oral presentation. The document must have the written approval for good English and writing style as well as correct content by the student's thesis advisor and a faculty member, not of the preliminary examination committee, who is appointed by the graduate program director. International students may need extensive writing assistance from the ESL Tutoring Center established to provide exactly this kind of technical writing tutorial support. Tutorial assistance in writing, if needed, will also be provided to native students.

F. Advancement to Candidacy

After successfully completing all requirements for the degree other than the dissertation, the student is eligible to be recommended for advancement to candidacy. This status is conferred by the Dean of the Graduate School upon recommendation from the graduate program director.

G. Dissertation

The most important requirement of the Ph.D. degree is the completion of a dissertation, which must be an original scholarly investigation. The dissertation must represent a significant contribution to the scientific literature and its quality must be comparable with the publication standards of appropriate and reputable scholarly journals.

H. Dissertation Defense

The student must defend the dissertation before an examining committee. On the basis of the recommendation of this committee, the Department of Applied Mathematics and Statistics will recommend acceptance or rejection of the dissertation to the Dean of the Graduate School. All requirements for the degree will have been satisfied upon successful defense of the dissertation. There must be at least one year between advancing to candidacy and scheduling a dissertation defense.

I. Minimum Residence

At least two consecutive semesters of full-time study are required.

J. Time Limit

All requirements for the Ph.D. degree must be completed within seven years after the completion of 24 graduate credits in the program. The time limits for the qualifying and preliminary examinations and advancement to candidacy are described in the Departmental *Graduate Student Handbook*.

K. Teaching Requirement

One academic year of teaching experience is required.

Courses

AMS 501 Differential Equations and Boundary Value Problems I

Examples of initial and boundary value problems in which differential equations arise. Existence and uniqueness of solutions, systems of linear differential equations, and the fundamental solution matrix. Power series solutions, Sturm-Louisville theory, eigenfunction expansion, Green's functions.
Prerequisite: AMS 505; recommended prerequisite AMS 504
Spring, 3 credits, ABCF grading

AMS 502 Differential Equations and Boundary Value Problems II

Analytic solution techniques for, and properties of solutions of, partial differential equations, with concentration on second order PDEs. Techniques covered include: method of characteristics, separation of variables, eigenfunction expansions, spherical means, Green's functions and fundamental solutions, and Fourier transforms. Solution properties include: energy conservation, dispersion, dissipation, existence and uniqueness, maximum and mean value principles.
Prerequisite: AMS 501
3 credits, ABCF grading

AMS 503 Applications of Complex Analysis

A study of those concepts and techniques in complex function theory that are of interest for their applications. Pertinent material is selected from the following topics: harmonic functions, calculus of residues, conformal mapping, and the argument principle. Application is made to problems in heat conduction, potential theory, fluid dynamics, and feedback systems.
Spring, 3 credits, ABCF grading

AMS 504 Foundations of Applied Mathematics

An introductory course for the purpose of developing certain concepts and techniques that are fundamental in modern approaches to the solution of applied problems. An appropriate selection of topics is based on the concepts of metric spaces, compactness, sequences and convergence, continuity, differentiation and integration, function sequences, contraction mapping theorem. Strong emphasis on proofs.
Fall, 3 credits, ABCF grading

AMS 505 Applied Linear Algebra

Review of matrix operations. Elementary matrices and reduction of general matrices by elementary operations, canonical forms, and inverses. Applications to physical problems. Coscheduled as AMS 505 or HPH 695.
Fall, 3 credits, ABCF grading

AMS 506 Finite Structures

Problem solving in combinatorial analysis and graph theory using generating functions, recurrence relations, Polya's enumeration formula, graph coloring, and network flows.
3 credits, ABCF grading

AMS 507 Introduction to Probability

The topics include sample spaces, axioms of probability, conditional probability and independence, discrete and continuous random variables, jointly distributed random variables, characteristics of random variables, law of large numbers and central limit theorem, Markov chains. Note: Crosslisted with HPH 696
3 credits, ABCF grading

AMS 510 Analytical Methods for Applied Mathematics and Statistics

Review of techniques of multivariate calculus, convergence and limits, matrix analysis, vector space basics, and Lagrange multipliers.
Prerequisite: A course in linear algebra and

in multivariate calculus
Fall, 3 credits, ABCF grading

AMS 511 Foundations of Quantitative Finance
Introduction to capital markets, securities pricing, and modern portfolio theory, including the organization and operation of securities market, the Efficient Market Hypothesis and its implications, the Capital Asset Pricing Model, the Arbitrage Pricing Theory, and more general factor models. Common stocks and their valuation, statistical analysis, and portfolio selection in a single-period, mean-variance context will be explored along with its solution as a quadratic program. Fixed income securities and their valuation, statistical analysis, and portfolio selection. Discussion of the development and use of financial derivatives. Introduction to risk neutral pricing, stochastic calculus, and the Black-Scholes Formula. Whenever practical, examples will use real market data. Numerical exercises and projects in a high-level programming environment will also be assigned.
3 credits, ABCF grading

AMS 512 Capital Markets and Portfolio Theory
Development of capital markets and portfolio theory in both continuous time and multi-period settings. Utility theory and its application to the determination of optimal consumption and investment policies. Asymptotic growth under conditions of uncertainty. Applications to problems in strategic asset allocation over finite horizons and to problems in public finance. Whenever practical, examples will use real market data. Numerical exercises and projects in a high-level programming environment will also be assigned.
Prerequisite: AMS 511
3 credits, ABCF grading

AMS 513 Financial Derivatives and Stochastic Calculus
Further development of derivative pricing theory including the use of equivalent martingale measures, the Girsanov Theorem, the Radon-Nikodym Derivative, and a deeper, more general understanding of the Arbitrage Theorem. Numerical approaches to solving stochastic PDE's will be further developed. Applications involving interest rate sensitive securities and more complex options will be introduced. Whenever practical, examples will use real market data. Numerical exercises and projects in a high-level programming environment will also be assigned.
Prerequisite: AMS 511
3 credits, ABCF grading

AMS 514 Computational Finance
Review of foundations: stochastic calculus, martingales, pricing, and arbitrage. Basic principles of Monte Carlo and the efficiency and effectiveness of simulation estimators. Generation of pseudo- and quasi-random numbers with sampling methods and distributions. Variance reduction techniques such as control variates, antithetic variates, stratified and Latin hypercube sampling, and importance sampling. Discretization methods including first and second order methods, trees, jumps, and barrier crossings. Applications in pricing American options, interest rate sensitive derivatives, mortgage-backed securities, and risk management. Whenever practical, examples will use real market data. Extensive numerical exercises and projects in a general programming environment will also be assigned.
Prerequisite: AMS 512 and AMS 513
3 credits, ABCF grading

AMS 515 Case Studies in Computational Finance
Actual applications of Quantitative Finance to problems of risk assessment, product design, portfolio management, and securities pricing will be covered. Particular attention will be paid to data collection and analysis, the design and implementation of software, and, most importantly, to differences that occur between "theory and practice" in model application, and to the development of practical strategies for handling cases in which "model failure" makes the naive use of quantitative techniques dangerous. Extensive use of guest lecturers drawn from the industry will be made.
Prerequisite: AMS 512 and AMS 513
3 credits, ABCF grading

AMS 520 Mathematical Modeling in the Analysis of Public Systems
Review of models relating to the questions of the improvement in delivery of urban service systems (e.g., fire, police, health, sanitation, transit). Topics include optimal location and districting of public facilities, distribution networks, models of congestion and delay in municipal services, and optimal deployment of emergency vehicles.
3 credits, ABCF grading

AMS 526 Numerical Analysis I
Direct and indirect methods for solving simultaneous linear equations and matrix inversion, conditioning, and round-off errors. Computation of eigenvalues and eigenvectors.
Co-requisite: AMS 505
Fall, 3 credits, ABCF grading

AMS 527 Numerical Analysis II
Numerical methods based upon functional approximation; polynomial interpolation and approximation; and numerical differentiation and integration. Solution methods for ordinary differential equations. AMS 527 may be taken whether or not the student has completed AMS 526.
Spring, 3 credits, ABCF grading

AMS 528 Numerical Analysis III
An introduction to scientific computation, this course considers the basic numerical techniques designed to solve problems of physical and engineering interest. Finite difference methods are covered for the three major classes of partial differential equations: parabolic, elliptic, and hyperbolic. Practical implementation will be discussed. The student is also introduced to the important packages of scientific software algorithms. AMS 528 may be taken whether or not the student has completed AMS 526 or AMS 527.
Spring, 3 credits, ABCF grading

AMS 530 Principles in Parallel Computing
This course is designed for both academic and industrial scientists interested in parallel computing and its applications to large-scale scientific and engineering problems. It focuses on the three main issues in parallel computing: analysis of parallel hardware and software systems, design and implementation of parallel algorithms, and applications of parallel computing to selected problems in physical science and engineering. The course emphasizes hands-on practice and understanding of algorithmic concepts of parallel computing.
Prerequisite: A course in basic computer science such as operating systems or architectures or some programming experience
Spring, 3 credits, ABCF grading

AMS 532 Laboratory Rotations and Journal Club in Computational Biology
This is a two-semester course in which students spend at least eight weeks in each of three different laboratories actively participating in the research of participating Computational Biology faculty. Participants will attend and give research talks at weekly Journal Club during the rotations. An overall grade is assigned and an evaluation form is completed by the supervising faculty member and provided to the student for constructive feedback.
Fall and Spring, 0 credit, S/U grading
May be repeated

AMS 533 Numerical Methods and Algorithms in Computational Biology
An in-depth survey of many of the key techniques used in diverse aspects of computational biology. A major focus of this class is on how to successfully formulate a statement of the problem to be solved, and how that formulation can guide in selecting the most suitable computational approach. Examples will be drawn from a wide range of problems in biology, including molecular modeling, biochemical reaction networks, microscopy, and systems biology. No prior knowledge of biology is required.
3 credits, ABCF grading

AMS 535 Introduction to Computational Structural Biology and Drug Design
This course will provide an introduction to computational structural biology with application to drug design. Methods and applications that use computation to model biological systems involved in human disease will be emphasized. The course aims to foster collaborative learning and will consist of presentations by the instructor, guest lecturers, and by course participants with the goal of summarizing key methods, topics, and papers relevant to computational structural biology.
Fall, 0-3 credits, ABCF grading
May be repeated for credit

AMS 536 Molecular Modeling of Biological Molecules
This course is designed for students who wish to gain hands-on experience modeling biological molecules at the atomic level. In conjunction with the individual interests, molecular mechanics, molecular dynamics, Monte Carlo, docking (virtual screening), or quantum mechanics software packages can be used to study relevant biological systems(s). Projects will include setup, execution, and analysis. Course

participants will give literature presentations relevant to the simulations being performed and a final project report will be required. Familiarity with UNIX (Linux) is desirable. This course is offered as both CHE 536 and AMS 536.
Prerequisite: CHE 535 or permission of instructor
Spring, 0-3 credits, ABCF grading
May be repeated for credit

AMS 537 Dynamical Models of Gene Regulation and Biological Pattern Formation
This is a graduate course in the fundamental theory of genetic function and biological pattern formation in animal development. The course covers dynamical (sometimes called physiological) models of these processes at a variety of mathematical levels. Biologically, the emphasis will be on *E. coli* and the fruit fly Drosophila, with a careful discussion of key experimental results for nonspcialists. We will study the use of both deterministic and stochastic differential equations to solve fundamental scientific problems such as the phage lambda lysis/lysogeny decision, the engineering of artificial gene circuits, and the determination and regulation of the morphogenetic field in animal development, particularly the segmentation field in Drosophila.
3 credits, ABCF grading

AMS 538 Methods in Neuronal Modeling
Presentation of the mathematical modeling approach to information processing in nervous systems, from the level of individual ionic channels to large-scale neuronal networks. The course covers kinetic models of synaptic transmission, cable theory and compartment models for neurons, multiple channels and calcium dynamics, spike-train analysis, and modeling small neuron networks.
3 credits, ABCF grading
May be repeated for credit

AMS 540 Linear Programming
Formulation of linear programming problems and solutions by simplex method. Duality, sensitivity analysis, dual simplex algorithm, decomposition. Applications to the transportation problem, two-person games, assignment problem, and introduction to integer and nonlinear programming. This course is offered as both MBA 540 and AMS 540.
Prerequisite: A course in linear algebra
3 credits, ABCF grading

AMS 542 Analysis of Algorithms
Techniques for designing efficient algorithms, including choice of data structures, recursion, branch and bound, divide and conquer, and dynamic programming. Complexity analysis of searching, sorting, matrix multiplication, and graph algorithms. Standard NP-complete problems and polynomial transformation techniques. This course is offered as both AMS 542 and CSE 548.
Prerequisite for CSE 548: CSE 373 recommended
Spring, 3 credits, ABCF grading

AMS 544 Discrete and Nonlinear Optimization
Theoretical and computational properties of discrete and nonlinear optimization problems: integer programming, including cutting plane and branch and bound algorithms, necessary and sufficient conditions for optimality of nonlinear programs, and performance of selected nonlinear programming algorithms. This course is offered as both MBA 544 and AMS 544.
Prerequisite: AMS 540 or MBA 540
Spring, 3 credits, ABCF grading

AMS 545 Computational Geometry
Study of the fundamental algorithmic problems associated with geometric computations, including convex hulls, Voronoi diagrams, triangulation, intersection, range queries, visibility, arrangements, and motion planning for robotics. Algorithmic methods include plane sweep, incremental insertion, randomization, divide-and-conquer, etc. This course is offered as both AMS 545 and CSE 555.
Prerequisite for CSE 555: CSE 373 or CSE 548
Spring, 3 credits, ABCF grading

AMS 546 Network Flows
Theory of flows in capacity-constrained networks. Topics include maximum flow, feasibility criteria, scheduling problems, matching and covering problems, minimum-length paths, minimum-cost flows, and associated combinatorial problems. This course is offered as both MBA 546 and AMS 546.
Prerequisite: AMS 540 or permission of instructor
Spring, 3 credits, ABCF grading

AMS 547 Discrete Mathematics
This course introduces such mathematical tools as summations, number theory, binomial coefficients, generating functions, recurrence relations, discrete probability, asymptotics, combinatorics, and graph theory for use in algorithmic and combinatorial analysis. This course is offered as both CSE 547 and AMS 547.
Prerequisite for CSE 547: AMS 301
Spring, 3 credits, ABCF grading

AMS 550 Operations Research: Stochastic Models
Includes Poisson processes, renewal theory, discrete-time and continuous-time Markov processes, Brownian motion, applications to queues, statistics, and other problems of engineering and social sciences. This course is offered as both MBA 550 and AMS 550.
Prerequisite: AMS 507 or equivalent
3 credits, ABCF grading

AMS 552 Game Theory I
Elements of cooperative and noncooperative games. Matrix games, pure and mixed strategies, and equilibria. Solution concepts such as core, stable sets, and bargaining sets. Voting games, and the Shapley and Banzhaff power indices. This course is offered as both ECO 604 and AMS 552.
Prerequisite for ECO 604: Graduate standing in the Department of Economics or permission of Graduate Director
0-3 credits, ABCF grading

AMS 553 Simulation and Modeling
A comprehensive course in formulation, implementation, and application of simulation models. Topics include data structures, simulation languages, statistical analysis, pseudorandom number generation, and design of simulation experiments. Students apply simulation modeling methods to problems of their own design. This course is offered as CSE 529, AMS 553, and MBA 553.
Prerequisite: CSE 214 or equivalent; AMS 310 or 507 or equivalent; or permission of instructor
3 credits, ABCF grading

AMS 554 Queuing Theory
Introduction to the mathematical aspects of congestion. Birth and death processes. Queues with service priorities and bulk-service queues. Analysis of transient- and steady-state behavior. Estimation of parameters. Applications to engineering, economic, and other systems. This course is offered as both MBA 554 and AMS 554.
Prerequisite: AMS 507
Fall, even years, 3 credits, ABCF grading

AMS 555 Game Theory II
Refinements of strategic equilibrium, games with incomplete information, repeated games with and without complete information, and stochastic games. The Shapley value of games with many players, and NTU-values. This course is offered as both ECO 605 and AMS 555.
Prerequisite for AMS 555: AMS 552/ECO 604. Prerequisites for ECO 605: ECO 604 and Graduate standing in the Department of Economics or permission of the Graduate Director.
Spring, 0-3 credits, ABCF grading

AMS 556 Dynamic Programming
Stochastic and deterministic multistage optimization problems. Stochastic path problems. Principle of optimality. Recursive and functional equations. Method of successive approximations and policy iteration. Applications to finance, economics, inventory control, maintenance, inspection, and replacement problems. This course is offered as both MBA 556 and AMS 556.
Prerequisite: MBA/AMS 550 or MBA/AMS 558
3 credits, ABCF grading

AMS 562 Numerical Hydrology
Numerical solution methods for the equations of incompressible flow in porous media with special emphasis on groundwater flow. Finite difference and finite element methods for steady-state and transient flows-boundary conditions, range of validity and stability of the numerical schemes, and numerical artifacts. The approach is hands on, with example problems being computed. This course is offered as both GEO 564 and AMS 562.
Prerequisite: AMS 526 or permission of instructor
Fall, alternate years, 3 credits, ABCF grading

AMS 565 Wave Propagation
Theory of propagation of vector and scalar waves in bounded and unbounded regions. Development of methods of geometrical optics. Propagation in homogeneous and

anisotropic media.
3 credits, ABCF grading

AMS 566 Compressible Fluid Dynamics
Physical, mathematical, and computational description in compressible fluid flows. Integral and differential forms of the conservation equations, one-dimensional flow, shocks and expansion waves in two and three dimensions, quasi-one-dimensional flow, transient flow, numerical methods for steady supersonic flow, numerical methods for transient flow.
Spring, 3 credits, ABCF grading

AMS 569 Probability Theory I
Probability spaces and sigma-algebras. Random variables as measurable mappings. Borel-Cantelli lemmas. Expectation using simple functions. Monotone and dominated convergence theorems. Inequalities. Stochastic convergence. Characteristic functions. Laws of large numbers and the central limit theorem. This course is offered as both AMS 569 and MBA 569.
Prerequisite: AMS 504 or equivalent
3 credits, ABCF grading

AMS 570 Introduction to Mathematical Statistics
Probability and distributions; multivariate distributions; distributions of functions of random variables; sampling distributions; limiting distributions; point estimation; confidence intervals; sufficient statistics; Bayesian estimation; maximum likelihood estimation; statistical tests.
Prerequisite: AMS 312 or equivalent
3 credits, ABCF grading

AMS 571 Mathematical Statistics
Sampling distribution; convergence concepts; classes of statistical models; sufficient statistics; likelihood principle; point estimation; Bayes estimators; consistency; Neyman-Pearson Lemma; UMP tests; UMPU tests; Likelihood ratio tests; large sample theory. Crosslisted as HPH 697 or AMS 571.
Prerequisite: AMS 312; AMS 570 is preferred but not required
3 credits, ABCF grading

AMS 572 Data Analysis I
Introduction to basic statistical procedures. Survey of elementary statistical procedures such as the t-test and chi-square test. Procedures to verify that assumptions are satisfied. Extensions of simple procedures to more complex situations and introduction to one-way analysis of variance. Basic exploratory data analysis procedures (stem and leaf plots, straightening regression lines, and techniques to establish equal variance). Coscheduled as AMS 572 or HPH 698.
Prerequisite: AMS 312 or permission of instructor
Fall, 3 credits, ABCF grading

AMS 573 Design and Analysis of Categorical Data
Measuring the strength of association between pairs of categorical variables. Methods for evaluating classification procedures and inter-rater agreement. Analysis of the associations among three or more categorical variables using log linear models. Logistic regression.
Prerequisite: AMS 572
Spring, 3 credits, ABCF grading

AMS 575 Internship in Statistical Consulting
Directed quantitative research problem in conjunction with currently existing research programs outside the Department. Students specializing in a particular area work on a problem from that area; others work on problems related to their interests, if possible. Efficient and effective use of computers. Each student gives at least one informal lecture to his or her colleagues on a research problem and its statistical aspects.
Prerequisite: Permission of instructor
3-4 credits, ABCF grading

AMS 577 Multivariate Analysis
The multivariate distribution. Estimation of the mean vector and covariance matrix of the multivariate normal. Discriminant analysis. Canonical correlation. Principal components. Factor analysis. Cluster analysis.
Prerequisites: AMS 572 and AMS 578
3 credits, ABCF grading

AMS 578 Regression Theory
Classical least-squares theory for regression including the Gauss-Markov theorem and classical normal statistical theory. An introduction to stepwise regression, procedures, and exploratory data analysis techniques. Analysis of variance problems as a subject of regression. Brief discussions of robustness of estimation and robustness of design.
Prerequisite: AMS 572 or equivalent
3 credits, ABCF grading

AMS 581 Analysis of Variance
Analysis of models with fixed effects. The Gauss-Markov theorem; construction of confidence ellipsoids and tests with Gaussian observations. Problems of multiple tests of hypotheses. One-way, two-way, and higher-way layouts. Analysis of incomplete designs such as Latin squares and incomplete blocks. Analysis of covariance problems.
Prerequisite: AMS 570 or equivalent
3 credits, ABCF grading

AMS 582 Design of Experiments
Discussion of the accuracy of experiments, partitioning sums of squares, randomized designs, factorial experiments, Latin squares, confounding and fractional replication, response surface experiments, and incomplete block designs. Coscheduled as AMS 582 or HPH 699.
Prerequisite: AMS 572 or equivalent
3 credits, ABCF grading

AMS 586 Time Series
Analysis in the frequency domain. Periodograms, approximate tests, relation to regression theory. Pre-whitening and digital fibers. Common data windows. Fast Fourier transforms. Complex demodulation, Gibbs' phenomenon issues. Time-domain analysis.
Prerequisites: AMS 507 and AMS 570
3 credits, ABCF grading

AMS 587 Nonparametric Statistics
This course covers the applied nonparametric statistical procedures: one-sample Wilcoxon tests, two-sample Wilcoxon tests, runs test, Kruskal-Wallis test, Kendall's tau, Spearman's rho, Hodges-Lehman estimation, Friedman analysis of variance on ranks. The course gives the theoretical underpinnings to these procedures, showing how existing techniques may be extended and new techniques developed. An excursion into the new problems of multivariate nonparametric inference is made.
Prerequisites: AMS 312 and AMS 572 or equivalents
Fall, 3 credits, ABCF grading

AMS 588 Biostatistics
Statistical techniques for planning and analyzing medical studies. Planning and conducting clinical trials and retrospective and prospective epidemiological studies. Analysis of survival times including singly censored and doubly censored data. Quantitative and quantal bioassays, two-stage assays, routine bioassays. Quality control for medical studies.
Prerequisite: AMS 572 or permission of instructor
Fall, 3 credits, ABCF grading

AMS 589 Quantitative Genetics
Definition of relevant terminology. Statistical and genetic models for inheritance of quantitative traits. Estimation of effects of selection, dominance polygenes, epistatis, and environment. Linkage studies and threshold characteristics.
Spring, odd years, 3 credits, ABCF grading

AMS 591 Topics for M.S. Students
Various topics of current interest in applied mathematics will be offered if sufficient interest is shown. Several topics may be taught concurrently in different sections.
Prerequisite: Permission of instructor
3 credits, ABCF grading
May be repeated for credit

AMS 592 Mathematical Methods of Finance and Investments I
A broad-based course in mathematical modeling and quantitative analysis of financial transactions and investment management issues such as debt and equity, measures of risk and returns, efficient markets and efficient set mathematics, asset pricing, one-factor and multiple-factor models, portfolio selection, futures and options.
Fall, 3 credits, ABCF grading

AMS 593 Mathematical Theory of Interest and Portfolio Pricing
Calculation of simple and compound interest poses elementary arithmetic or algebraic problems. Variable interest rates (including indexing), inflation, changes in the exchange rates of foreign currency, and changes in the laws, such as income tax, create investment risks. The course is intended to develop problem-solving skills and adopts both deterministic and stochastic approaches. The perspectives of the consumer and the investor are taken into account. The material helps students prepare for the actuarial examinations. Topics are selected from the following: simple and compound interest, fixed-rate loans and mortgages, annuities and capital

budgeting of pension plans, variable interest rates, bonds, prepayment and default scenarios, and currency baskets.
Prerequisite: AMS 310 or permission of instructor
Fall, 3 credits, ABCF grading

AMS 594 Mathematical Methods of Finance and Investments II
This course employs the techniques of mathematical statistics and empirical finance, e.g., estimation theory, linear and nonlinear regression, time series analysis, modeling and simulation to examine critically various models of prediction for asset-pricing, pricing of derivative products and term-structure of interest rates assuming stochastic volatility. Statistics necessary for analysis is incorporated in the course.
Prerequisite: AMS 592
Fall, 3 credits, ABCF grading

AMS 595 Fundamentals of Computing
Introduction to UNIX operating system, C language, graphics, and parallel supercomputing.
Fall, 1 credit, ABCF grading

AMS 596 Fundamentals of Large-Scale Computing
Overview of the design and maintenance of large-scale computer projects in applied mathematics, including basic programming techniques for massively parallel supercomputers.
Prerequisite: AMS 595 or permission of instructor
Spring, 1 credit, ABCF grading

AMS 597 Statistical Computing
Introduction to statistical computing using SAS and S plus.
Fall, 1 credit, ABCF grading

AMS 599 Research
1-12 credits, S/U Grading
May be repeated for up to 12 credits

AMS 605 Probability Theory II
Advanced probability. Conditional sigma-fields, stochastic processes, Brownian motion, Markov property, weak convergence, infinitely divisible distributions, martingales, stochastic integrals, stochastic differential equations, and stochastic approximation.
Prerequisite: AMS 569 or permission of instructor
3 credits, ABCF grading

AMS 607 Advanced Stochastic Processes I
Theory and application of continuous time stochastic processes, continuous time martingales, square-integrable martingales, Brownian motion, stochastic integrals and Ito's formula, stochastic differential equations, and applications to financial mathematics.
Prerequisite: AMS 605 or AMS 569
Spring, 3 credits, ABCF grading

AMS 615 Advanced Stochastic Processes II
Existence, uniqueness, and continuity theorems. Approximate solutions by method of iteration. Study of autonomous systems. Phase-plane analysis, periodic solutions. Singular points, cycles, and limit cycles. Theory of bifurcation. Stability theory and Liapunov functions. Analytical and geometrical investigations of second-order equations such as van der Pol's and Lienard's equations.
Prerequisite: AMS 501
3 credits, ABCF grading

AMS 620 Theory and Applications of Large-Scale Networks
A rigorous treatment of mathematical techniques used to answer many practical questions arising in the study and design of large-scale networks. Emphasis on the development of algorithms. Several lectures devoted to specific applications to computer networks to be used throughout the course.
Prerequisite: AMS 540 or equivalent
3 credits, ABCF grading

AMS 621 Finite Element Methods for Partial Differential Equations
Variational form of the problem, Ritz Galerkin, collocation, and mixed methods; triangular, rectangular (2-D), and tetrahedral (3-D) elements; accuracy, convergence, and stability; solutions of linear, nonlinear steady-state, and dynamic problems; implicit and explicit time integration; equivalence of finite-element and finite-difference methods.
Prerequisite: AMS 502 or equivalent
3 credits, ABCF grading

AMS 623 Topics in Systems and Control Theory
This course is designed for second- and third-year graduate students who wish to pursue research in the area of systems and control theory. The students are expected to have a strong research background in linear algebra and differential equations and basic knowledge in systems and control theory.
Prerequisite: Permission of instructor
Spring, 3 credits, ABCF grading
May be repeated for credit

AMS 627 Theory of Integral Equations and Their Applications
Integral equations with degenerate kernels, equations of the second kind, iterative solutions, contraction mapping principle, Fredholm theory, and spectral theory for symmetric kernels. Volterra equations of the first and second kind, equations with weakly singular kernels, simultaneous systems, and applications.
Prerequisites: AMS 504 and AMS 505
3 credits, ABCF grading

AMS 628 Applications of Functional Analysis
Introduction to such topics as unbounded operators and the closed-graph theorem, convexity, weak convergence in Hilbert space, and degree theory. Applications to monotone operators and the stability of nonlinear systems, to Schwartz distributions and passive linear systems, and to the solution of nonlinear equations.
Prerequisite: AMS 504 or equivalent
3 credits, ABCF grading

AMS 641 Special Topics in Mathematical Programming
The course is designed for second- and third-year graduate students with a strong foundation in linear algebra and analysis who wish to pursue research in applied mathematics. Varying topics from nonlinear programming and optimization to applied graph theory and applied combinatorics may be offered concurrently.
Prerequisites: AMS 540 and permission of instructor
3 credits, ABCF grading
May be repeated for credit

AMS 644 Special Topics in Applied Probability
The course is designed for second- and third-year graduate students with a background in probability and stochastic modeling who wish to pursue research in applications of the probability theory. Several topics may be taught concurrently in different sections.
Prerequisites: AMS 550 and permission of instructor
Fall, 3 credits, ABCF grading
May be repeated for credit

AMS 651 Nonlinear Analysis and Optimization
Iterative methods for solving nonlinear operator equations. Frechet differentials. The Newton-Raphson method in function space and nonlinear boundary value problems. The Courant penalty concept and constrained optimization. General multiplier rules. Variable metric gradient projection for nonlinear least-square methods, with applications.
3 credits, ABCF grading

AMS 652 Special Topics in Game Theory
The course is designed for second- and third-year graduate students who wish to specialize in the mathematical theory of games.
Prerequisites: AMS 552 and permission of instructor
3 credits, ABCF grading
May be repeated for credit

AMS 670 Special Topics in Probability and Mathematical Statistics
The course is designed for second- and third-year graduate students with a strong foundation in analysis and statistics who wish to pursue research in mathematical statistics. Several topics may be taught concurrently in different sections.
Prerequisites: AMS 569, AMS 570
3 credits, ABCF grading
May be repeated for credit

AMS 675 Special Topics in Applied Statistics
The course is designed for second- and third-year students with a strong foundation in statistical analysis who wish to pursue research in applied statistics.
Prerequisites: AMS 507, AMS 572
3 credits, ABCF grading
May be repeated for credit

AMS 676 Internship in Applied Mathematics
Directed research and/or practical experience in industry, financial and consulting firms, and research institutions. Students are required to have a Department faculty adviser who coordinates and supervises the internship. Submission of the final report is required.
0-9 credits, S/U grading

AMS 683 Biological Physics and Biophysical Chemistry: Theoretical Perspectives

This course will survey a selected number of topics in biological physics and biophysical chemistry. The emphasis is on the understanding of physical organization principles and fundamental mechanisms involved in the biological process. The potential topics include: Protein Folding, Protein Dynamics, Biomolecular Interactions and Recognition, Electron and Proton Transfer, Motors, Membranes, Single Molecules and Single Cells, Cellular Networks, Development and Differentiation, Brains and Neural Systems, Evolution. There will be no homework or exams. The grades will be based on the performance of the term projects. Crosslisted with PHY 680 and CHE 683.

0-3 credits, ABCF grading

AMS 690 Special Topics in Differential Equations and Applied Analysis

The course is designed for second- and third-year graduate students with a strong foundation in analysis who wish to pursue research in applied mathematics. Several topics may be taught concurrently in different sections.

Prerequisites: AMS 501, AMS 504

3 credits, ABCF grading

May be repeated for credit

AMS 691 Topics in Applied Mathematics

Varying topics selected from the list below if sufficient interest is shown. Several topics may be taught concurrently in different sections:

Advanced Operational Methods in Applied Mathematics
Approximate Methods in Boundary Value Problems in Applied Mathematics
Control Theory and Optimization
Foundations of Passive Systems Theory
Game Theory
Mixed Boundary Value Problems in Elasticity
Partial Differential Equations
Quantitative Genetics
Stochastic Modeling

3 credits, ABCF grading

May be repeated for credit

AMS 695 Special Topics in Numerical Analysis and Scientific Computing

The course is designed for second- and third-year graduate students with a strong foundation in applied linear algebra and numerical analysis who wish to pursue research in applied mathematics. Several topics may be taught concurrently in different sections.

Prerequisites: AMS 505, AMS 526

3 credits, ABCF grading

May be repeated for credit

AMS 698 Practicum in Teaching

3 credits, S/U Grading

May be repeated for credit

AMS 699 Dissertation Research On Campus

Prerequisite: Must be advanced to candidacy (G5); major portion of research must take place on SB campus, at Cold Spring Harbor, or at Brookhaven National Lab

Fall, spring, and summer, 1-9 credits, S/U grading

May be repeated for credit

AMS 700 Dissertation Research Off Campus—Domestic

Prerequisite: Must be advanced to candidacy (G5); major portion of research will take place off-campus, but in the U.S. and/or U.S. provinces (Brookhaven National Lab and Cold Spring Harbor Lab are considered on campus); all international students must enroll in one of the graduate student insurance plans and should be advised by an International Advisor

Fall, spring, summer, 1-9 credits, S/U grading

May be repeated for credit

AMS 701 Dissertation Research off Campus–International

Prerequisite: Must be advanced to candidacy (G5); major portion of research will take place outside of the U.S. and/or U.S. provinces; domestic students have the option of the health plan and may also enroll in MEDEX; international students who are in their home country are not covered by mandatory health plan and must contact the Insurance Office for the insurance charge to be removed; international students who are not in their home country are charged for the mandatory health insurance (if they are to be covered by another insurance plan, they must file a waiver by the second week of classes; the charge will only be removed if the other plan is deemed comparable); all international students must receive clearance from an International Advisor

Fall, spring, summer, 1-9 credits, S/U grading

May be repeated for credit

AMS 800 Summer Research

0 credit, S/U grading

May be repeated