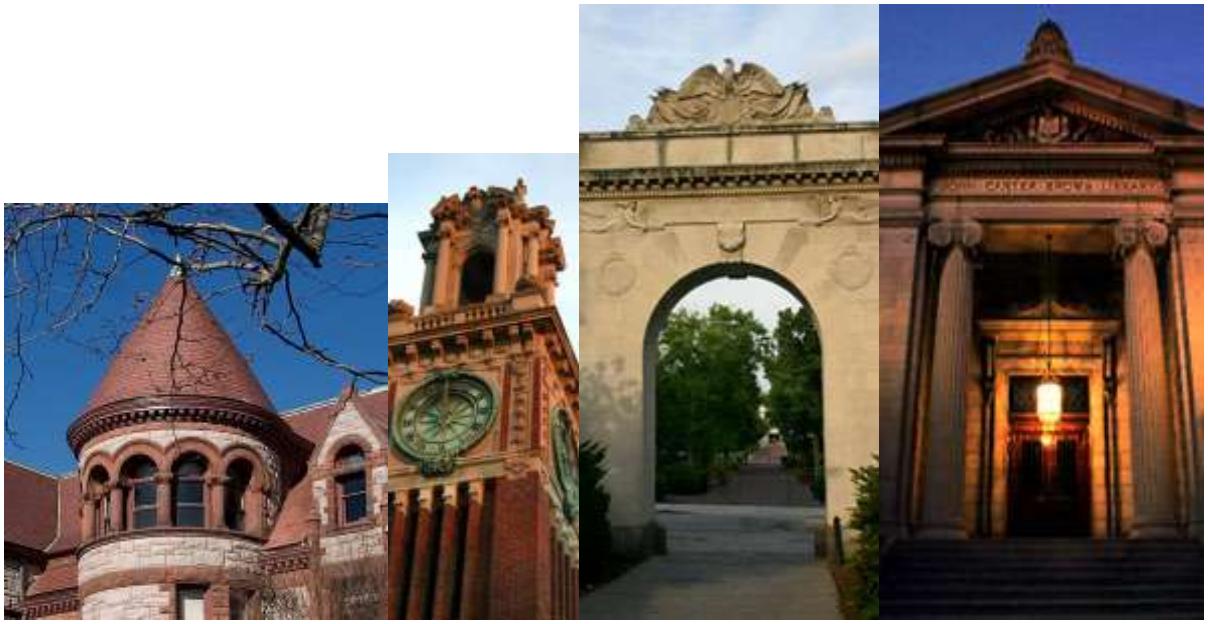

BROWN UNIVERSITY
Division of Applied Mathematics
Graduate Program Brochure

Revised October 9, 2009

BROWN UNIVERSITY OVERVIEW

Brown University, founded in 1764, is the seventh oldest institution of higher learning in America and one of the major universities in the nation. With an enrollment of 5,600 undergraduates and 1,300 graduate students it combines a university's emphasis on scholarship and research with a college's commitment to education and attention to the individual student. Brown awards degrees in virtually all areas of the humanities, the physical, biological and social sciences, mathematics and computer science. The Division of Applied Mathematics is one of the most prominent departments of the University, and one of the oldest and strongest of its type in the country.

ORIGIN OF THE DIVISION OF APPLIED MATHEMATICS

The Division had its origin in a program of Advanced Instruction and Research in Mechanics, established in the summer of 1941 on the recommendation of a committee of the National Research Council. The Council was concerned with the lack of applied mathematicians in the country and its effect on the war effort. R. G. D. Richardson, Dean of the Graduate School and Secretary of the American Mathematical Society, succeeded in having the program established at Brown, partly due to the eminence of its Mathematics Department. A large part of the European scientific community had left Europe by then, and the time was ripe for establishing a substantial program in the United States. Dean Richardson arranged for the noted German applied mathematician William Prager to come to Brown to lead the program. About 30 students attended in the first year, 1941, and enrollment rose to about 120 one year later. The roster of visiting faculty during the war years reads like a Who's Who of American mathematical science of that time. On the recommendation of a committee appointed by Brown's President Henry M. Wriston, and including Theodore von Karman, Marston Morse and Warren Weaver, the very successful program became the Graduate Division of Applied Mathematics in 1946, and a formal Ph.D. program was established. Undergraduate programs leading to the Sc.B. and to the A.B. were added in the 1950s.

The early program in applied mathematics focused on solid and fluid mechanics, electromagnetic theory, mathematical methods in applied physics, numerical analysis and probability theory—the principal interests of the faculty for many years. Since that time, the interests of the faculty have been extended as the Division has maintained a leading role in the development of applied mathematics. In 1964, for example, the Center for Dynamical Systems was established to coordinate the research of a large group of people working in ordinary and partial differential equations and their applications. More recently, strong programs of research in scientific computing and in applied probability and statistics have been established.

GRADUATE PROGRAM RESEARCH AREAS

The Division of Applied Mathematics is devoted to training and research in a broad spectrum of applied mathematics. It explores the connections between mathematics and its applications at both the research and the educational levels. The principal areas of research activities are ordinary, functional, and partial differential equations; stochastic control theory; applied probability, statistics and stochastic systems theory; neuroscience and computational biology; numerical analysis and scientific computation; and the mechanics of solids and fluids. The effort in virtually all the research areas ranges from applied and algorithmic problems to the study of fundamental mathematical questions. This breadth is one of the great strengths of the program.

Scholarship and research in the Division of Applied Mathematics are augmented by many points of contact with the Department of Mathematics and the Division of Engineering, including joint appointments, courses, and research projects. There are also collaborative research projects and joint courses with faculty in the Departments of Computer Science, Biostatistics, Economics, Geological Sciences and Neuroscience, as well as with faculty in the Medical School. Some of the areas in which there are cooperative research projects with other departments include partial differential equations, fluid and solid mechanics, robotics and computer vision, scientific and parallel computing, stochastic systems theory and medical statistics.

Research in the areas of differential equations and dynamical systems focuses on the qualitative properties of solutions of the nonlinear differential equations that arise in the physical sciences, biological sciences and economics. A great variety of differential equations is being studied: ordinary, functional (with delays), and partial, including fluid equations, hyperbolic conservation laws, kinetic equations, reaction-diffusion systems and relativistic wave equations. Even though the techniques can vary widely from case to case, a unifying philosophy in the approach has been generated by the great Brown tradition in this area of mathematics and is being fostered by close collaboration among the members of the group.

Research in stochastic control and optimization includes virtually all of the problem areas of current interest: optimization methods, stability and the qualitative theory of stochastic dynamical systems, small-noise problems, singular perturbations, approximation methods, stochastic networks and data processing systems, methods of large deviations, applications to queuing networks, applications to financial and economic models, nonlinear filtering, recursive stochastic algorithms and their applications in communication and adaptive control theory, asymptotic methods, singular control problems, problems with wide-band noise, control under partial information and heavy traffic approximations. There is a major program in numerical methods for all of the problem types.

Research in applied probability and statistics emphasizes image processing, computer and biological vision, and related complex problems in statistical inference. Algorithms are developed, based on mathematical models, for restoration, enhancement, reconstruction, and high-level analysis of digital images. The mathematical models, predominantly probabilistic and pattern-theoretic in nature, enable the use of classical statistical principles as a foundation.

Considerable attention is given to the applications of the methods to real data, in areas such as medical imaging, industrial automation, and design of intelligent systems for object detection and recognition. Closely related work is concerned with other complex signal processing and inference problems including, for example, speech recognition. Other statistically oriented work concerns the analysis of data from problems in medicine and health care.

Research focuses on statistical inference in high dimensions with applications primarily in molecular biology but also in the geosciences. The development of novel inference principles, methods, and algorithms appropriate to the special characteristics of high-dimensional discrete spaces are the main activities. Challenging high dimensional statistical inference problems emerging from the sequencing of genomes and from numerous high throughput data acquisition technologies of the post genome era provide the focus of the largest component of our research. In addition, sequences of data emerging form paleoclimatology studies of the earth’s history are another important application area. Bayesian statistical approaches dominated our work, and we generally employ either direct sampling strategies using recursive equations to obtain key normalizing constants, or Markov chain Monte Carlo (MCMC) algorithms. All of our work involves real applications in collaboration with biologic and geologic investigators at Brown and beyond, and all of our theoretical studies have been motivated by these applications.

Research in fluid mechanics focuses on problems in complex fluids, bioflows, microflows, and oceanography. Specific applications include multiscale modeling of the human arterial tree, aneurisms, and blood rheology. Some further topics of interest are the dynamic self-assembly of micro and nanoscale particles in suspension, active suspensions of micro-swimmers, and the flow properties of such systems. Other aspects include uncertainty quantification in computational mechanics, noisy flow systems, and low-dimensional modeling. Both continuum as well as atomistic simulation methods are employed with high-performance computing required in most applications.

Scientific computing, as a science and as a method of research, is inherently multidisciplinary. It has undergone phenomenal growth in response to the successes of modern computational methods in increasing understanding of fundamental problems in science and engineering. The Division’s program in scientific computation and numerical analysis has kept pace with these developments and relates to most of the other research activities in the Division. Special emphasis has been given to newly developed high-order techniques for the solution of the linear and nonlinear partial differential equations that arise in control theory and fluid dynamics. Numerical methods for the discontinuous problems that arise in shock wave propagation are being studied. Emphasis is also being placed on the solution of large-scale linear systems and on the use of parallel processors in linear and nonlinear problems.

A large number of regular seminars cover the principal areas of scientific interest in the Division. Some involve speakers from all over the world, and others are used to augment the formal courses by providing expositions of special topics in a short series of lectures. The research seminars are an integral part of the graduate program.

The Division typically has a large number of postdoctoral and faculty visitors who actively contribute to research programs and graduate education. It is not uncommon for the visiting researchers to outnumber the regular faculty.

RESEARCH CENTERS AND GROUPS

The Division is not formally structured into isolated research groups; instead, it emphasizes applied mathematics as a unifying theme in its own right. However, in order to facilitate cooperation among faculty and students, some of the research programs are partly organized around several interdepartmental research centers. On the whole, the centers are loosely organized with many joint affiliations and interaction among them. The centers facilitate funding and cooperative research and help to maintain at the highest level the research and educational atmosphere of the Division.

The funding of these research centers supports several positions for long and short-term postdoctoral visitors in the Division. There is also a special endowment from IBM to support visitors from industrial and governmental laboratories.

Lefschetz Center for Dynamical Systems

The Lefschetz Center provides a unique environment in which high-level mathematical research is carried out alongside intensive collaborations with researchers in the applied sciences and engineering. The Center is named after the famous mathematician, Solomon Lefschetz, who was one of its founders and early leaders. Faculty and students from the Division of Applied Mathematics, Department of Mathematics, and Division of Engineering with common interests in the theory and applications of nonlinear analysis are brought together through the activities of the center. The research of the group is focused on modern approaches to dynamical systems, partial differential equations (particularly nonlinear wave propagation and conservation laws) and stochastic control. Mathematical techniques are developed and applied in a broad range of fields, including continuum mechanics, mathematical biology, nonlinear optics, economics and finance, oceanography, celestial mechanics, fluids and astrophysics.

Center for Fluid Mechanics, Turbulence and Computation

The Center for Fluid Mechanics, Turbulence and Computation was established in 1986 when the university received an award from DARPA for a Center of Excellence in the Study of Turbulence. The Center attracts distinguished visiting scientists and provides a strong program for graduate students and postdoctoral fellows. Its research is concerned with experimental, theoretical and computational problems in fluid mechanics, with emphasis on turbulence and transitional flows in a variety of physical applications. The Center has established a well-equipped computing facility maintained by its own staff. The computing facility includes resources acquired by faculty throughout the Division and is used by the whole Division. Sophisticated methods of scientific computation and computer graphics are used in large-scale simulations, management of very large databases, and visualization of complex fluid flows. It recently acquired an IBM SP2 supercomputer, a state-of-the-art 24-

node parallel processor, which is one of the most powerful computers available anywhere. The facility is linked to the national supercomputer centers and accessible by participating members over the campus network. There is also a well-instrumented wind tunnel, maintained by the Division of Engineering, for the study of turbulence and transition.

CRUNCH GROUP

The CRUNCH group is a research group in the Division of Applied Mathematics. The thrust of its research is the development of numerical algorithms, visualization methods and parallel software for continuum and atomistic simulations in fluid mechanics and related applications. The main approach to numerical discretization is based on spectral/*hp* element methods, on multi-element polynomial chaos, and on stochastic molecular dynamics (DPD). The group is directed by Prof. George Em Karniadakis.

PATTERN THEORY GROUP

The Brown University pattern theory group is working with the belief that the world is complex, and to understand it, or a part of it, requires realistic representations of knowledge about it. We create such representations using a mathematical formalism, pattern theory that is compositional in that the representations are built from simple primitives, combined into (often) complicated structures according to rules that can be deterministic or random. This is similar to the formation of molecules from atoms connected by various forms of bonds. Pattern theory is transformational in that groups or semigroups of transformations operate on the primitives. These transformations express the invariances of the worlds we are looking at. Pattern theory is variational in that it describes the variability of the phenomena observed in different applications in terms of probability measures that are used with a Bayesian interpretation. This leads to inferences that will be realized by computer algorithms. Our aim is to realize them through codes that can be executed on currently available hardware.

SCIENTIFIC COMPUTING GROUP

The Scientific Computing and Numerical Analysis group has its particular strength in the analysis and application of high order numerical methods including spectral and spectral element methods, discontinuous Galerkin finite element methods, ENO and WENO finite difference and finite volume methods, compact and other high-order finite difference methods. The applications of these methods span wide including modeling and analysis of problems in computational biology, electromagnetics, high speed flows, material science, semiconductor device simulations as well as problems in optical communication systems and fiberoptics to name a few.

In addition to these Centers, the Division of Applied Mathematics also cooperates actively with Computation and Mathematics of Mind (CMM), The Center for Computational Molecular Biology (CCMB), Institute for Brain and Neural Systems, the Center for Biophysical and Biomedical Engineering, the Center for Gerontology and Health Care Research and the Center for Statistical Science, the latter two being operated by the Brown

University School of Medicine. These affiliations reflect growing interest in the Division with the applications of mathematics to the nonphysical sciences.

DIVISION OF APPLIED MATHEMATICS FACULTY

ELIE BIENENSTOCK
Associate Professor of Applied Mathematics and Neuroscience
Theoretical neuroscience, artificial vision
Ph.D., Brown University, 1980

FREDERIC BISSHOPP
Professor Emeritus of Applied Mathematics
Asymptotics, nonlinear wave propagation, fluid mechanics
Ph.D., University of Chicago, 1959

CONSTANTINE M. DAFERMOS
Alumni-Alumnae University Professor of Applied Mathematics, Chair of Graduate Program
Continuum mechanics and the theory of partial differential equations, especially nonlinear hyperbolic systems of conservation laws with solutions containing shock waves
Ph.D., John Hopkins University, 1967

PHILIP DAVIS
Professor Emeritus of Applied Mathematics
Numerical analysis, approximation theory, interpolation and approximation, philosophy of mathematics
Ph.D., Harvard University, 1950

HONGJIE DONG
Assistant Professor of Applied Mathematics
Partial differential equations, nonlinear elliptic and parabolic PDEs, Navier-Stokes equations, quasi-geostrophic equations, reaction diffusion equations, unique continuation problems, stochastic processes, numerical analysis
Ph.D., University of Minnesota, 2005

PAUL DUPUIS
Professor and Chair of Applied Mathematics
Applied probability, control theory, large deviations, numerical methods, stochastic systems and networks
Ph.D., Brown University, 1985

PETER FALB
Professor Emeritus of Applied Mathematics
Control and stability theory, mathematics of investment
Ph.D., Harvard University, 1961

WENDELL FLEMING
Professor Emeritus of Applied Mathematics
Applied probability, stochastic differential equations, control theory
Ph.D., University of Wisconsin-Madison, 1951

WALTER FREIBERGER
Professor Emeritus of Applied Mathematics and Professor of Applied Mathematics (Research)
Statistics and biostatistics
Ph.D., University of Cambridge, 1953

STUART GEMAN
James Manning Professor of Applied Mathematics, Graduate Program Advisor
Compositional vision, neural representation, and neural computation
Ph.D., Massachusetts Institute of Technology, 1977

BASILIS GIDAS
Professor of Applied Mathematics
Computer vision, speech recognition, computational molecular biology and nonparametric statistics
Ph.D., University of Michigan-Ann Arbor, 1970

ULF GRENANDER
Professor Emeritus of Applied Mathematics and Professor of Applied Mathematics (Research)
Pattern theory
Ph.D., University of Stockholm, 1948

YAN GUO
Professor of Applied Mathematics
Partial differential equations, kinetic theory, stability theory and stellar dynamics
Ph.D., Brown University, 1993

JOHNNY GUZMAN
Assistant Professor of Applied Mathematics
Numerical analysis of partial differential equations and scientific computing; Local behavior of numerical methods; Discontinuous Galerkin methods for second order elliptic problems, Stokes systems, singularly perturbed problems, conservation laws, and elasticity; Hybridizable and mixed finite element methods; Elliptic problems on nonsmooth domains
Ph.D., Cornell University, 2005

MATTHEW HARRISON
Assistant Professor of Applied Mathematics
Statistics: conditional inference, multiple hypothesis testing, sequential importance sampling.
Neuroscience: pattern detection in multi-neuronal spiking data, exploratory data analysis.

Information theory: rate distortion theory, model selection. Computer vision: structured statistical models, natural scene statistics, perceptual organization.
Ph.D., Brown University, 2005

JAN HESTHAVEN
Associate Chair and Professor of Applied Mathematics
Numerical analysis, scientific computing, computational electromagnetics, fluid dynamics
Ph.D., Technical University of Denmark, 1995

DIN-YU HSIEH
Professor Emeritus and Professor of Applied Mathematics (Research)
Fluid mechanics, mathematical physics.
Ph.D., California Institute of Technology, 1960

GEORGE KARNIADAKIS
Professor of Applied Mathematics, Graduate Program Advisor
Scientific computing, computational fluid dynamics, stochastic differential equations
Ph.D., Massachusetts Institute of Technology, 1987

HAROLD KUSHNER
Professor Emeritus of Applied Mathematics Professor of Applied Mathematics (Research)
Stochastic control and stability, nonlinear filtering, applications to communications theory, nonlinear filtering, numerical methods, heavy traffic approximations to queuing and communications networks
Ph.D., University of Wisconsin, 1958

CHARLES LAWRENCE
Professor of Applied Mathematics, Undergraduate Program Advisor
Identification of subtle sequence signals in non-coding DNA, RNA structure prediction, models for inferences on gene regulation, Bayesian inference in computational molecular biology, associated algorithms, prokaryotic transcription regularly networks, mechanisms of eukaryotic gene regulation
Ph.D., Cornell University, 1971

JOHN MALLET-PARET
Professor of Applied Mathematics, Director of Lefschetz Center for Dynamical Systems
Ordinary and functional differential equations
Ph.D., University of Minnesota, 1974

MARTIN MAXEY
Professor of Applied Mathematics and Engineering
Dynamics of two-phase flow, turbulence, and particle/micro-flow systems
Ph.D., University of Cambridge

DONALD McCLURE
Professor Emeritus of Applied Mathematics
Pattern analysis, image processing, mathematical statistics
Ph.D., Brown University, 1970

GOVIND MENON
Associate Professor of Applied Mathematics, Chair, Undergraduate Program
Dynamical systems, partial differential equations, and materials science
Ph.D., Brown University, 2001

DAVID MUMFORD
University Professor of Applied Mathematics (Emeritus)
Pattern theory, biological and computer vision
Ph.D., Harvard University, 1961

BORIS ROZOVSKY
Professor of Applied Mathematics, Undergraduate Program Advisor
Stochastic partial differential equations and applications to fluid dynamics, nonlinear filtering and stochastic numerics.
Ph.D., Moscow State (Lomonosov) University, 1972.

BJŐRN SANDSTEDE
Professor of Applied Mathematics
Applied dynamical systems and partial differential equations posed on extended domains. Dynamics of patterns, coherent structures, and nonlinear waves, using a mixture of analytical and geometric dynamical-systems techniques together with numerical computations.
Ph.D., University of Stuttgart, 1993

CHI-WANG SHU
Professor of Applied Mathematics, Graduate Program Advisor
Numerical solutions of conservation laws and in general convection dominated problems using finite difference essential non-oscillatory (ENO) methods and weighted ENO (WENO) methods, finite element discontinuous Galerkin methods, spectral methods, computational fluid dynamics, numerical solutions of equations appearing in semi-conductor device simulations, numerical solutions of Hamilton-Jacobi type equations
Ph.D., University of California at Los Angeles, 1986

WALTER STRAUSS
Professor of Applied Mathematics and Mathematics
Nonlinear waves, scattering theory, partial differential equations, mathematical physics, stability theory, solitary waves, kinetic theory of plasmas, water waves, dispersive waves
Ph.D., Massachusetts Institute of Technology, 1962

CHAU-HSING SU
Professor of Applied Mathematics, and Undergraduate Program Advisor
Fluid mechanics, water waves, stochastic processes
Ph.D., Princeton University, 1964

HUI WANG
Associate Professor of Applied Mathematics, Graduate Program Advisor
Stochastic analysis, stochastic optimization, stochastic networks and simulation
Ph.D., Columbia University, 2000

THE DOCTORAL PROGRAM

Requirements for Ph.D. in Applied Mathematics

Satisfactory progress for Ph.D. students in the Division of Applied Mathematics requires:

1) ***The student must complete all first year basic courses with satisfactory grades (all B or above, and with no more B's than A's).***

2) ***The student must successfully locate an advisor who has explicitly agreed to supervise the student's thesis work during the second year of study.***

3) ***The student must successfully pass both the major and minor preliminary exams by the end of their third year of study.***

4) ***The student must complete their dissertation within 6 years.***

The Department's large collection of courses enables the student to get a deep and state-of-the-art understanding of their field of specialization, while at the same time acquiring an excellent background in other relevant areas of applied mathematics. On arrival, the student is assigned a faculty advisor, who will help the student choose the appropriate courses. The first year's program aims to fill whatever gaps there are in the student's background, as well as to provide the foundations in analysis and in other basic subjects which are necessary preparation for the more specialized courses in the following years. There is often enough time in the first year for some course work in the area of intended specialization, if that is known. The intellectual demands on applied mathematicians in university research as well as in industrial research and development are continually changing. It is essential that a program be chosen with both the `long view' as well as the more immediate demands of impending research in mind.

Much of the course work is oriented towards the requirements of the preliminary examination. This examination is oral (possibly augmented by a small written part) and is commonly taken at about the fifth semester in residence here, although it can be taken earlier if the student has had prior preparation. The examination covers one major and two minor subjects. The major subject is usually close to the field in which the student will be doing his or her doctoral research. The student will be expected to show breadth of knowledge as well as the depth of understanding. The subjects will be chosen with the advice and consent of the faculty advisor, and must be approved by the departmental committee on graduate affairs. The subjects for the examination are normally selected from standard groups which have been found to give a good preparation for careers in the different areas, although approved variations are allowed. The systems are flexible, provided that the basic intellectual goals are met.

After the preliminary examination has been passed, the student normally spends most of his or her time on thesis research. The student is, however, urged to continue to do some course work in order to assure the best possible background as well as the best preparation for thesis research.

Every candidate for the Ph.D. degree is required to engage in at least one year's teaching as a teaching assistant. This refers to the actual performance of actual teaching duties, not to the forms of financial aid. The Harriet W. Sheridan Center for Teaching and Learning offers a broad range of programs, lectures, and services for the Brown teaching community. Of particular interest to graduate TAs are: the Teaching Certificate Programs, Individual Consultation Services (including teaching, presentation, course, syllabus and grant consultations), the Teaching Seminar Lectures & Forums, and a wide variety of on-line handbooks and workshops. For more information, please visit the Sheridan Center’s website: http://www.brown.edu/sheridan_center .

After completing the thesis and having it approved by two readers appointed by the faculty advisor, the student presents the research results publicly and has a final oral defense of the thesis.

Graduates have been very successful in finding jobs in the most prestigious universities and industrial or governmental laboratories.

THE MASTERS PROGRAM

The emphasis in the Division of Applied Mathematics is on programs leading to the Ph.D., and financial support is given only to qualified students who are working towards that degree. Nevertheless, the instructional and research offerings of the Division afford rich possibilities for master's degree programs for those who are preparing for careers in industry or government or who will seek teaching jobs that do not require the Ph.D., and who wish to improve their background in any of the various areas of applied mathematics. The following requirements are to be met in order to receive the Master's of Science Degree in the Division of Applied Mathematics:

1. A total of 8 courses must be satisfactorily completed. At least 6 of them must be Applied Mathematics courses.
2. At least 6 of the 8 courses must be taken at the 200 level.
3. A maximum of 2 C's are allowed among the 8 courses.
4. Research courses are reading courses (among them APMA 2910, 2920, and 2990) are not acceptable for fulfillment of requirements. However, seminar courses

(APMA 2810 and APMA 2820), which meet regularly and have regular homework assignments and exams are acceptable.

5. Any course taken for the Sc.M. degree should have a grade assigned (i.e. - it cannot be taken Sat/NC).
6. With permission from the Graduate Program Chair, one course (with grade) can be transferred for credit from another University.

Course Program

(Note: Some courses are not offered every year.)

Courses for Undergraduates and Graduates

APMA 1070. Quantitative Models of Biological Systems (BIOL 1490)
An introduction to the use of quantitative modeling techniques in solving problems in biology. Each year one major biological area is explored in detail from a modeling perspective. The particular topic will vary from year to year. Mathematical techniques will be discussed as they arrive in the context of biological problems. Prerequisites: Introductory Level Biology, APMA 0330, APMA 0340, or APMA 0350, APMA 0360, or written permission.

APMA 1080. Inference in Genomics and Molecular Biology
Traditional and Bayesian statistical inferences on biopolymer data including; sequence alignment; structure prediction; regulatory signals; significances of searches; phylogeny; and functional genomics. Emphasis is on discrete high dimensional objects common in field. Statistical topics: parameter estimation; hypothesis testing and false discovery rates; statistical decision theory; and Bayesian posterior inference. Prerequisites: APMA 1650 and BIOL 1470 or BIOL 1500, and programming experience minimally Matlab.

APMA 1170. Introduction to Computational Linear Algebra
Focuses on fundamental algorithms in computational linear algebra with relevance to all science concentrators. Basic linear algebra and matrix decompositions (Cholesky, LU, QR, etc.), round-off errors and numerical analysis of errors and convergence. Iterative methods and conjugate gradient techniques. Computation of eigenvalues and eigenvectors, and an introduction to least squares methods. A brief introduction to Matlab is given. Prerequisites: MATH 0520 is recommended, but not required.

APMA 1180. Introduction to the Numerical Solution of Partial Differential Equations
Fundamental numerical techniques for solving ordinary and partial differential equations. Overview of techniques for approximation and integration of functions. Development of

multistep and multistage methods, error analysis, step-size control for ordinary differential equations. Solution of two-point boundary value problems, introduction to methods for solving linear partial differential equations. Introduction to Matlab is given but some programming experience is expected. Prerequisites: APMA 0330, 0340 or 0350, 0360. APMA 1170 is recommended.

APMA 1200. Operational Analysis: Probabilistic models
Basic probabilistic problems and methods in operations research and management science. Methods of problem formulation and solution. Markov chains, birth-death processes, stochastic service and queuing systems, the theory of sequential decisions under uncertainty, dynamic programming. Applications. Prerequisite: APMA 1650 or MATH 1610, or equivalent.

APMA 1210. Operations Research: Deterministic Methods (ENGN 1310)
An introduction to the basic mathematical ideas and computational methods of optimizing allocation of effort or resources, with or without constraints. Linear programming, network models, dynamic programming, and integer programming.

APMA 1330. Methods of Applied Mathematics III, IV
Review of vector calculus and curvilinear coordinates. Partial differential equations. Heat conduction and diffusion equations, the wave equation, Laplace and Poisson equations. Separation of variables, special functions, Fourier series and power series solution of differential equations. Sturm-Liouville problem and eigenfunction expansions.

APMA 1360. Topics in Chaotic Dynamics
Overview and introduction to dynamical systems. Local and global theory of maps. Attractors and limit sets. Lyapunov exponents and dimensions. Fractals: definition and examples. Lorentz attractor, Hamiltonian systems, homoclinic orbits and Smale horseshoe orbits. Chaos in finite dimensions and in PDEs. Can be used to fulfill the senior seminar requirement in applied mathematics. Prerequisites: Differential equations and linear algebra.

APMA 1650. Statistical Inference I
APMA 1650 begins an integrated first course in mathematical statistics. The first half of APMA 1650 covers probability and the last half is statistics, integrated with its probabilistic foundation. Specific topics include probability spaces, discrete and continuous random variables, methods for parameter estimation, confidence intervals, and hypothesis testing. Prerequisite: MATH 0100 or its equivalent.

APMA 1660. Statistical Inference II

APMA 1660 is designed as a sequel to APMA 1650 to form one of the alternative tracks for an integrated year's course in mathematical statistics. The main topic is linear models in statistics. Specific topics include likelihood-ratio tests, nonparametric tests introduction to statistical computing, matrix approach to simple-linear and multiple regression, analysis of variance, and design of experiments. Prerequisite: APMA 1650 or equivalent, basic linear algebra.

APMA 1670. Statistical Analysis of Time Series

Time series analysis is an important branch of mathematical statistics with many applications to signal processing, econometrics, geology, etc. The course emphasizes methods for analysis in the frequency domain, in particular, estimation of the spectrum of a time-series, but time domain methods are also covered. Prerequisite: elementary probability and statistics on the level of APMA 1650-1660. Offered in alternate years.

APMA 1680. Nonparametric Statistics

A systematic treatment of the distribution-free alternatives to classical statistical tests. These non-parametric tests make minimum assumptions about distributions governing the generation of observations, yet are of nearly equal power to the classical alternatives. Prerequisite: APMA 1650 or equivalent.

APMA 1690. Computational Probability and Statistics

Examination of probability theory and statistical inference from the point of view of modern computing. Random number generation, Monte Carlo methods, simulation, and other special topics. Prerequisites: calculus, linear algebra, APMA 1650, or equivalent. Some experience with programming desirable.

APMA 1700. The Mathematics of Insurance

The course consists of two parts. The first treats life contingencies, i.e., the construction of models for individual life insurance contracts. The second treats the Collective Theory of Risk, which constructs mathematical models for the insurance company and its portfolio of policies as a whole. Suitable also for students proceeding to the Institute of Actuaries examinations. Prerequisites: Probability to the level of APMA 1650 or MATH 1610. Offered in alternate years.

APMA 1710. Information Theory (CSCI 1850, ENGN 1510)

Information theory is the study of the fundamental limits of information transmission and storage. This course, intended primarily for advanced undergraduates, and beginning graduate students, offers a broad introduction to information theory and its applications: Entropy and information; lossless data compression, communication in the presence of noise, capacity, channel coding; source-channel separation; lossy data compression.

APMA 1930, APMA 1940. Senior Seminars

Independent study and special topics seminars in various branches of applied mathematics, ***change from year to year***. Recent topics include Mathematics of Speculation, Scientific Computation, Coding and Information Theory, Topics in Chaotic Dynamics, and Software for Mathematical Experiments. The following courses have been offered in past semesters. For current listings, please see BANNER.

APMA 1930A. Actuarial Mathematics

A seminar considering selected topics from two fields: (1) life contingencies-the study of the valuation of life insurance contracts; and (2) collective risk theory, which is concerned with the random process that generates claims for a portfolio of policies. Topics are chosen from *Actuarial Mathematics*, 2nd ed., by Bowers, Gerber, Hickman, Jones, and Nesbitt. Prerequisite: knowledge of probability theory to the level of AM 165 or MA 161. Particularly appropriate for students planning to take the examinations of the Society of Actuaries

APMA 1930B. Computational Probability and Statistics

Examination of probability theory and mathematical statistics from the perspective of computing. Topics selected from: random number generation, Monte Carlo methods, limit theorems, stochastic dependence, Bayesian networks, probabilistic grammars

APMA 1930C. Information Theory

Information theory is the mathematical study of the fundamental limits of information transmission (or coding) and storage (or compression). This course offers a broad introduction to information theory and its real-world applications. A subset of the following is covered: entropy and information; the asymptotic equipartition property; theoretical limits of lossless data compression and practical algorithms; communication in the presence of noise-channel coding, channel capacity; source-channel separation; Gaussian channels; Lossy data, compression.

APMA 1930D. Mixing and Transport in Dynamical Systems

Mixing and transport are important in several areas of applied science, including fluid mechanics, atmospheric science, chemistry, and particle dynamics. In many cases, mixing seems highly complicated and unpredictable. We use the modern theory of dynamical systems to understand and predict mixing and transport from the differential equations describing the physical process in question. Prerequisites: AM 33,34 or AM 35,36.

APMA 1930E. Ocean Dynamics

Works through the popular book by Henry Stommel entitled *A View of the Sea.* Introduces the appropriate mathematics to match the physical concepts introduced in the book.

APMA1930G. The Mathematics of Sports

Topics to be discussed will range from the determination of who won the match, through biomechanics, free-fall of flexible bodies and aerodynamics, to the flight of ski jumpers and similar unnatural phenomena. Prerequisites: AM 11 and AM 34 or their equivalents, or permission of the instructor.

APMA 1930H. Scaling and Self-Similarity

The themes of scaling and self-similarity provide the simplest, and yet the most fruitful description of complicated forms in nature such as the branching of trees, the structure of human lungs, rugged natural landscapes, and turbulent fluid flows. This seminar is an investigation of some of these phenomena in a self-contained setting requiring a little more mathematical background than high school algebra. Topics to be covered: Dimensional analysis, empirical laws in biology, geosciences, and physics and the interplay between scaling and function; an introduction to fractals; social networks and the “small world” phenomenon.

APMA 1940. Senior Seminar

APMA 1940A. Coding and Information Theory

In a host of applications, from satellite communication to compact disc technology, the storage, retrieval, and transmission of digital data relies upon the theory of coding and information for efficient and error-free performance. This course is about choosing representations that minimize the amount of data (compression) and the probability of an error in data handling (error-correcting codes). Prerequisite: A knowledge of basic probability theory at the level of AM 165 or MA 161.

APMA 1940B. Information and Coding Theory

Originally developed by C.E. Shannon in the 1940s for describing bounds on information rates across telecommunication channels, information and coding theory is now employed in a large number of disciplines for modeling and analysis of problems that are statistical in nature. This course provides a general introduction to the field. Main topics include entropy, error correcting codes, source coding, data compression. Of special interest will be the connection to problems in pattern recognition. Includes a number of projects relevant to neuroscience, cognitive and linguistic sciences, and computer vision. Prerequisites: High school algebra, calculus. MATLAB or other computer experience helpful. Prior exposure to probability theory/statistics helpful.

APMA1940C. Introduction to Mathematics of Fluids

Equations that arise from the description of fluid motion are born in physics, yet are interesting from a more mathematical point of view as well. Selected topics from fluid dynamics introduce various problems and techniques in the analysis of partial differential equations. Possible topics include stability, existence and uniqueness of solutions, variational problems, and active scalar equations. No prior knowledge of fluid dynamics is necessary.

APMA 1940D. Iterative Methods
Large, sparse systems of equations arise in many areas of mathematical application and in this course we explore the popular numerical solution techniques being used to efficiently solve these problems. Throughout the course we will study preconditioning strategies, Krylov subspace acceleration methods, and other projection methods. In particular, we will develop a working knowledge of the Conjugate Gradient and Minimum Residual (and Generalized Minimum Residual) algorithms. Multigrid and Domain Decomposition Methods will also be studied as well as parallel implementation, if time permits.

APMA 1940E. Mathematical Biology
This course is designed for undergraduate students in mathematics who have an interest in the life sciences. No biological experience is necessary, as we begin by a review of the relevant topics. We then examine a number of case studies where mathematical tools have been successfully applied to biological systems. Mathematical subjects include differential equations, topology and geometry.

APMA 1940F. Mathematics of Physical Plasmas
Plasmas can be big, as in the solar wind, or small, as in fluorescent bulbs. Both kinds are described by the same mathematics. Similar mathematics describes semiconducting materials, the movement of galaxies, and the re-entry of satellites. We consider how all of these physical systems are described by certain partial differential equations. Then we invoke the power of mathematics. The course is primarily mathematical. Prerequisites: AM 34 or 36, MA 18 or 20 or 35, and PH 6 or PH 8 or EN 51.

APMA 1940G. Multigrid Methods
Mulitgrid methods are a very active area of research in Applied Mathematics. An introduction to these techniques will expose the student to cutting-edge mathematics and perhaps pique further interest in the field of scientific computation.

APMA 1940H. Numerical Linear Algebra
This course will deal with advanced concepts in numerical linear algebra. Among the topics covered: Singular Value Decompositions (SVD) QR factorization, Conditioning and Stability and Iterative Methods.

APMA 1940I. The Mathematics of Finance
The mathematics of speculation as reflected in the securities and commodities markets. Particular emphasis placed on the evaluation of risk and its role in decision-making under uncertainty. Prerequisite: basic probability.

APMA 1940J. The Mathematics of Speculation

The course will deal with the mathematics of speculation as reflected in the securities and commodities markets. Particular emphasis will be placed on the evaluation of risk and its role in decision making under uncertainty. Prerequisite: basic probability.

APMA 1940K. Fluid Dynamics and Physical Oceanography

Introduction to fluid dynamics as applied to the mathematical modeling and simulation of ocean dynamics and near-shore processes. Oceanography topics include: overview of atmospheric and thermal forcing of the oceans, ocean circulation, effects of topography and Earth's rotation, wind-driven currents in upper ocean, coastal upwelling, the Gulf Stream, tidal flows, wave propagation, tsunamis.

APMA 1940L. Mathematical Models in Biophysics

Introduction to reaction models for biomolecules, activation and formation of macro-molecules, stochastic simulation methods such as Langevin models and Brownian dynamics. Applications to blood flow, platelet aggregation, and interactions of cells with blood vessel walls.

APMA 1940M. The History of Mathematics

The course will not be a systematic survey but will focus on specific topics in the history of mathematics such as Archimedes and integration, Oresme and graphing, Newton and infinitesimals, simple harmonic motion, the discovery of ‘Fourier’ series, the Monte Carlo method, reading and analyzing the original texts. A basic knowledge of calculus will be assumed.

APMA 1940N. Mathematical Models in Computational Biology.

This course is designed to introduce students to the use of mathematical models in biology as well as some more recent topics in computational biology. Mathematical techniques will involve difference equations and dynamical systems theory ordinary differential equations and some partial differential equations. These techniques will be applied in the study of many biological applications as (i) Difference equations: population dynamics, red blood cell production, population genetics; (ii) Ordinary differential equations: Predator-prey models, Lotka-Volterra model, modeling and evolution of the genome, heart beat model/cycle, transmission dynamics of HIV and gonorrhea; (iii) Partial differential equations: tumor growth, modeling evolution of the genome, pattern formation. Prerequisites: APMA 0330 and APMA 0340.

APMA 1940O. Approaches to Problem Solving in Applied Mathematics

The aim of the course is to illustrate through the examination of unsolved (but elementary) problems the ways in which professional applied Mathematicians approach the solution of such questions. Ideas considered include: choosing the “simplest” nontrivial example, generalization and specification. Ways to think outside convention. Some knowledge of probability and linear algebra helpful. Suggested reading: “How to solve it,” by G. Polya and “Nonplussed,” by Julian Havil.

APMA 1940P. Biodynamics of Block Flow and Cell Locomotion

APMA 1970. Independent Study

GRADUATE LEVEL COURSES

APMA 2050, APMA 2060. Mathematical Methods of Applied Science Introduces science and engineering graduate students to a variety of fundamental mathematical methods. Topics include linear algebra, complex variables, Fourier-series, Fourier and Laplace transforms and their applications, ordinary differential equations, tensors, curvilinear coordinates, integral equations, partial differential equations, and calculus of variations.

APMA 2110. Real Analysis (MATH 2210)

Provides the basis of real analysis which is fundamental to many of the other courses in the program: metric spaces, measure theory, and the theory of integration and differentiation.

APMA 2120. Hilbert Spaces and Their Applications (MATH 2220)

A continuation of APMA 2110: Metric spaces, Banach spaces, Hilbert spaces, the spectrum of bounded operators on Banach and Hilbert spaces, compact operators, applications to integral and differential equations.

APMA 2130. Methods of Applied Mathematics: Partial Differential Equations

Solution methods and basic theory for first and second order partial differential equations. Geometric interpretation and solution of linear and nonlinear first order equations by characteristics; formation of caustics and propagation of discontinuities. Classification of second order equations and issues of well-posed problems. Green's functions and maximum principles for elliptic systems. Characteristic methods and discontinuous solutions for hyperbolic systems.

APMA 2140. Methods of Applied Mathematics: Integral Equations

Integral equations. Fredholm and Volterra theory, expansions in orthogonal functions, theory of Hilbert-Schmidt. Singular integral equations, method of Wiener-Hopf. Calculus of variations and direct methods.

APMA 2160. Methods of Applied Mathematics: Asymptotics
Calculus of asymptotic expansions, evaluation of integrals. Solution of linear ordinary differential equations in the complex plane, WKB method, special functions. May be taken concurrently with APMA 2140.

APMA 2170. Functional Analysis and Applications
Topics vary according to interest of instructor and class.

APMA 2190, APMA 2200. Nonlinear Dynamical Systems: Theory and Applications
Basic theory of ordinary differential equations, flows, and maps. Two-dimensional systems. Linear systems. Hamiltonian and integrable systems. Lyapunov functions and stability. Invariant manifolds, including stable, unstable, and center manifolds. Bifurcation theory and normal forms. Nonlinear oscillations and the method of averaging. Chaotic motion, including horseshoe maps and the Melnikov method. Applications in the physical and biological sciences.

APMA 2210. Topics in Differential Equations
A variety of topics in nonlinear dynamics, based in part on the interests of the students, will be covered. Among the possible topics are: bifurcation theory, degree theory, infinite-dimensional systems, delay-differential equations, exponential dichotomies, skew-product flows, and monotone dynamical systems. The prerequisite for the course is a solid (rigorous) grounding in nonlinear dynamics, typically APMA 2190-2200 or equivalent.

APMA 2230, APMA 2240. Partial Differential Equations (MATH 2370, 2380)
The theory of the classical partial differential equations; the method of characteristics and general first order theory. The Fourier transform, the theory of distributions, Sobolev spaces, and techniques of harmonic and functional analysis. More general linear and nonlinear elliptic, hyperbolic, and parabolic equations and properties of their solutions, with examples drawn from physics, differential geometry, and the applied sciences. Semester II concentrates on special topics chosen by the instructor.

APMA 2260. Introduction to Stochastic Control Theory
This course serves as an introduction to the theory of stochastic control and dynamic programming technique. Optimal stopping, total expected (discounted) cost problems, and long-run average cost problems will be discussed in discrete time setting. The last part of the course deals with continuous time deterministic control and game problems. The course requires some familiarity with probability theory.

APMA 2270, APMA 2280. Topics in the Control of Systems
Topics will vary from year to year, but will include optimal control theory, computational methods for control, and algebraic methods in systems science.

APMA 2330. Foundations of Continuum Mechanics (ENGN 2210)
An introduction to the mathematical foundations of continuum mechanics. Vectors and tensors, properties and basic operations. Kinematics of deformation. Conservation laws, thermodynamics. Stress. Constitutive equations. Elastic, viscous, and viscoelastic response. Linearization. Simple problems in finite and linear elasticity, and in Navier-Stokes flows. Creep and relaxation in linear viscoelasticity.

APMA 2340. Linear Elasticity (ENGN 2240)
General theorems in linear elasticity. Basic singular solutions. Boussinesq-Papkovich and Galerkin representations. Curvilinear coordinates. Cavity, inclusion, crack and contact problems. States of plane strain, plane stress, and axial symmetry. Complex variable techniques. Torsion. Thermoelasticity.

APMA 2350. Advanced Elasticity (ENGN 2270)
Large elastic deformations. Controllable deformations of incompressible materials. Initial stress problems. Elastic stability. Additional topics may include membrane theory, fiber-reinforced materials, second-order elasticity.

APMA 2360. Topics in Continuum Mechanics (ENGN 2280)
Advanced topics such as finite elasticity theory, initial stress problems, elastic stability, quasiconvexification in membrane theory, and mechanics of fiber-reinforced materials.

APMA 2370. Plasticity (ENGN 2290)
Theory of the inelastic behavior of materials with negligible time effects. Experimental background for metals and fundamental postulates for plastic stress-strain relations. Variational principles for incremental elastic-plastic problem, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory. Representative problems in structural analysis, metal forming, indentation, strain and stress concentrations at notches, and ductile failure.

APMA 2380. Stress Waves in Solids (ENGN 2260)
Interested students should register for ENGN 2260.

APMA 2390. Viscoelasticity (ENGN 2250)
Interested students should register for ENGN 2250.

APMA 2410. Fluid Dynamics I (ENGN 2810)
An introduction to fundamental concepts of the mechanics and thermodynamics of fluid flow. Major topics include compressible and incompressible flows, viscous and inviscid flows, and vorticity dynamics.

APMA 2420. Fluid Dynamics II (ENGN 2820)
A continuation of APMA 2410. Topics include: Low Reynolds number flows, boundary layer theory, wave motion, stability and transition, acoustics, and compressible flows.

APMA 2470, APMA 2480. Topics in Fluid Dynamics
Initial review of topics selected from flow stability, turbulence, turbulent mixing, surface tension effects, and thermal convection. Followed by focused attention on the dynamics of dispersed two-phase flow and complex fluids.

APMA 2550. Numerical Solution of Partial Differential Equations I
Finite difference methods for solving time-depend initial value problems of partial differential equations. Fundamental concepts of consistency, accuracy, stability and convergence of finite difference methods will be covered. Associated well-posedness theory for linear time-dependent PDEs will also be covered. Some knowledge of computer programming expected.

APMA 2560. Numerical Solution of Partial Differential Equations II
Examines the development and analysis of spectral methods for the solution of time-dependent partial differential equations. Topics include key elements of approximation and stability theory for Fourier and polynomial spectral methods as well as attention to temporal integration and numerical aspects. Some knowledge of computer programming expected.

APMA 2570. Numerical Solution of Partial Differential Equations III
We will cover finite element methods for ordinary differential equations and for elliptic, parabolic and hyperbolic partial differential equations. Algorithm development, analysis, and computer implementation issues will be addressed. In particular, we will discuss in depth the discontinuous Galerkin finite element method.

APMA 2580. Computational Fluid Dynamics
An introduction to computational fluid dynamics with emphasis on incompressible flows. Reviews the basic discretization methods (finite differences and finite volumes) following a pedagogical approach from basic operators to the Navier-Stokes equations. Suitable for first-year graduate students, more advanced students, and senior undergraduates. Requirements include three to four computer projects. Material from APMA 1170 and APMA 1180 is appropriate as prerequisite, but no prior knowledge of fluid dynamics is necessary.

APMA 2610. Recent Applications of Probability and Statistics
This is a topics course, covering a selection of modern applications of probability and statistics in the computational, cognitive, engineering, and neural sciences. The course will be rigorous, but the emphasis will be on application. Topics will likely include:

Markov chains and their applications to MCMC computing and hidden Markov models; Dependency graphs and Bayesian networks; parameter estimation and the EM algorithm; Kalman and particle filtering; Nonparametric statistics ("learning theory"), including consistency, bias/variance tradeoff, and regularization; the Bayesian approach to nonparametrics, including the Dirichlet and other conjugate priors; principle and independent component analysis; Gibbs distributions, maximum entropy, and their connections to large deviations. Each topic will be introduced with several lectures on the mathematical underpinnings, and concluded with a computer project, carried out by each student individually, demonstrating the mathematics and the utility of the approach. There will be no exams.

APMA 2630, APMA 2640. Theory of Probability (MATH 2630, MATH 2640)
A two-semester course in probability theory. Semester I includes an introduction to probability spaces and random variables, the theory of countable state Markov chains and renewable processes, laws of large numbers and the central limit theorems. Measure theory is first used near the end of the first semester (APMA 2110 may be taken concurrently). Semester II provides a rigorous mathematical foundation to probability theory and covers conditional probabilities and expectations, limit theorems for sums of random variables. martingales, ergodic theory, Brownian motion and an introduction to stochastic process theory.

APMA 2660. Stochastic Processes
Review of the theory of stochastic differential equations and reflected SDEs, and of the ergodic and stability theory of these processes. Introduction to the theory of weak convergence of probability measures and processes. Concentrates on applications to the probabilistic modeling, control, and approximation of modern communications and queuing networks; emphasizes the basic methods, which are fundamental tools throughout applications of probability.

APMA 2670. Mathematical Statistics I
Advanced Statistical Inference. Emphasis on the theoretical aspects of the subject. Frequentist and Bayesian approaches, and their interplay. Topics include: general theory of inference, point and set estimation, hypothesis testing, and modern computational methods (E-M Algorithm, Markov Chain Monte Carlo, Bootstrap). Students should have prior knowledge of probability theory, at the level of APMA 2630 or higher.

APMA 2680. Mathematical Statistics II
This course provides a solid presentation of modern nonparametric statistical methods. Topics include: density estimation, adaptive smoothing, cross-validation, bootstrap, classification and regression trees and their connection to the Huffman code, projection pursuit, the ACE algorithm for time series prediction, support vector machines, and learning theory. The course will provide the mathematical underpinnings, but it will also

touch upon some applications in computer vision/speech recognition, and biological, neural, and cognitive sciences. Prerequisite: APMA 2760

APMA 2690, APMA 2700. Topics in Statistics and its Applications
Advanced topics varying from year to year, including: non-parametric methods for density estimation, regression and prediction in time-series; cross-validation and adaptive smoothing techniques; bootstrap; recursive partitioning, projection-pursuit, ACE algorithm; non-parametric classification and clustering; stochastic Metropolis-type simulation and global optimization algorithms; Markov random fields and statistical mechanics; applications to image processing, speech recognition and neural networks.

APMA 2720. Information Theory
Information theory and its relationship with probability, statistics, and data compression. Entropy. The Shannon-McMillan-Breiman theorem. Shannon's source coding theorems. Statistical inference; hypothesis testing; model selection; the minimum description length principle. Information-theoretic proofs of limit theorems in probability: Law of large numbers, central limit theorem, large deviations, Markov chain convergence, Poisson approximation, Hewitt-Savage 0-1 law. Prerequisites: APMA 2630; APMA 1710.

APMA 2810. Seminars in Applied Mathematics Topics Courses
Graduate level seminars in various branches of applied mathematics ***change from year to year***. APMA 2810 Topics Courses are offered during the Fall semester, and APMA 2820 Topics Courses are offered during the Spring semester. The following courses have been offered in past semesters, however for current listings, please see BANNER.

APMA 2810A. Computational Biology
Provides an up-to-date presentation of the main problems and algorithms in bioinformatics. Emphasis is given to statistical/probabilistic methods for various molecular biology tasks, including, comparison of genomes of different species, finding genes and motifs, understanding transcription control mechanisms, analyzing microarray data for gene clustering, and predicting RNA structure.

APMA 2810B. Computational Molecular Biology
Provides an up-to-date presentation of problems and algorithms in bioinformatics, beginning with an introduction to biochemistry and molecular genetics. Topics include: proteins and nucleic acids, the genetic code, the central dogma, the genome, gene expression, metabolic transformations, and experimental methods (gel electrophoresis, X-ray crystallography, NMR). Also, algorithms for DNA sequence alignment, database search tools (BLAST), and DNA sequencing.

APMA 2810C. Elements of High Performance Scientific Computing

APMA 2810D. Elements of High Performance Scientific Computing, II

APMA 2810E. Far Field Boundary Conditions for Hyperbolic Equations

APMA 2810F. Introduction to Non-linear Optics

APMA 2810G. Large Deviations

APMA 2810H. Math of Finance

APMA 2810I. Mathematical Models and Numerical Analysis in Computational Quantum Chemistry.
We shall present on some models in the quantum chemistry field (Thomas Fermi and related, Hartree Fock, Kohn Sham) the basic tools of functional analysis for the study of their solutions. Then some of the discretization methods and iterative algorithms to solve these problems will be presented and analyzed. Some of the open problems that flourish in this field will also be presented all along the lectures.

APMA 2810J. Mathematical Techniques for Neural Modeling

APMA 2910K. Methods of Algebraic Geometry in Control Theory I
Develops the ideas of algebraic geometry in the context of control theory. The first semester examines scalar linear systems and affine algebraic geometry while the second semester addresses multivariable linear systems and projective algebraic geometry.

APMA 2810L. Numerical Solution of Hyperbolic PDE's

APMA 2810M. Some Topics in Kinetic Theory
Nonlinear instabilities as well as boundary effects in a collisionless plasmas; Stable galaxy configurations; A nonlinear energy method in the Boltzmann theory will also be introduced. Self-contained solutions to specific concrete problems. Focus on ideas but not on technical aspects. Open problems and possible future research directions will then be discussed so that students can gain a broader perspective. Prerequisite: One semester of PDE (graduate level) is required.

APMA 2810N. Topics in Nonlinear PDEs
Aspects of the theory on nonlinear evolution equations, which includes kinetic theory, nonlinear wave equations, variational problems, and dynamical stability.

APMA 2810O. Stochastic Differential Equations

This course develops the theory and some applications of stochastic differential equations. Topics include: stochastic integral with respect to Brownian motion, existence and uniqueness for solutions of SDEs, Markov property of solutions, sample path properties, Girsanov's Theorem, weak existence and uniqueness, and connections with partial differential equations. Possible additional topics include stochastic stability, reflected diffusions, numerical approximation, and stochastic control. Prerequisite: APMA 2640

APMA 2810P. Perturbation Methods

Basic concepts of asymptotic approximations with examples with examples such as evaluation of integrals and functions. Regular and singular perturbation problems for differential equations arising in fluid mechanics, wave propagation or nonlinear oscillators. Methods include matched asymptotic expansions and multiple scales. Methods and results will be discussed in the context of applications to physical problems.

APMA 2810Q. Discontinuous Galerkin Methods

In this seminar course we will cover the algorithm formulation, stability analysis and error estimates, and implementation and applications of discontinuous Galerkin finite element methods for solving hyperbolic conservation laws, convection diffusion equations, dispersive wave equations, and other linear and nonlinear partial differential equations. Prerequisite: AM 255.

APMA 2810R. Computational Biology Methods for Gene/Protein Networks and Structural Proteomics

The course presents computational and statistical methods for gene and protein networks and structural proteomics; it emphasizes: (1) Probablistic models for gene regulatory networks via microarray, chromatin immune-precipitation, and cis-regulatory data; (2) Signal transduction pathways via tandem mass spectrometry data; (3) Molecular Modeling forligand-receptor coupling and docking. The course is recommended for graduate students.

APMA 2810S. Topics in Control

APMA 2810T. Nonlinear Partial Differential Equations

This course introduces techniques useful for solving many nonlinear partial differential equations, with emphasis on elliptic problems. PDE from a variety of applications will be discussed. Contact the instructor about prerequisites.

APMA 2810U. Topics in Differential Equations

APMA 2810V. Topics in Partial Differential Equations

The course will cover an introduction of the L_p theory of second order elliptic and parabolic equations, finite difference approximations of elliptic and parabolic equations, and some recent developments in the Navier-Stokes equations and quasi-geotropic equations. Some knowledge of real analysis will be expected.

APMA 2810W. Advanced Topics in High Order Numerical Methods for Convection Dominated Problems
This is an advanced seminar course. We will cover several topics in high order numerical methods for convection dominated problems, including methods for solving Boltzmann type equations, methods for solving unsteady and steady Hamilton-Jacobi equations, and methods for solving moment models in semi-conductor device simulations. Prerequisite: APMA 2550 or equivalent knowledge of numerical analysis.

APMA 2810Z. An Introduction to the Theory of Large Deviations
The theory of large deviations attempts to estimate the probability of rare events and identify the most likely way they happen. The course will begin with a review of the general framework, standard techniques (change-of-measure, subadditivity, etc.), and elementary examples (e.g., Sanov's and Cramer's Theorems). We then will cover large deviations for diffusion processes and the Wentsel-Freidlin theory. The last part of the course will be one or two related topics, possibly drawn from (but not limited to) risk-sensitive control; weak convergence methods; Hamilton-Jacobi-Bellman equations; Monte Carlo methods. Prerequisites: AM 263 and 264.

APMA 2811A. Directed Methods in Control and System Theory. Various general techniques have been developed for control and system problems. Many of the methods are indirect. For example, control problems are reduced to a problem involving a differential equation (such as the partial differential equation of Dynamic Programming) or to a system of differential equations (such as the canonical system of the Maximum Principle). Since these indirect methods are not always effective alternative approaches are necessary. In particular, direct methods are of interest. We deal with two general classes, namely: 1.) Integration Methods; and, 2.) Representation Methods. Integration methods deal with the integration of function space differential equations. Perhaps the most familiar is the so-called Gradient Method or curve of steepest descent approach. Representation methods utilize approximation in function spaces and include both deterministic and stochastic finite element methods. Our concentration will be on the theoretical development and less on specific numerical procedures. The material on representation methods for Levy processes is new.

APMA 2820. Seminar in Applied Mathematics Topics Courses
Graduate level seminars in various branches of applied mathematics ***change from year to year***. The below mentioned courses are typically offered during the Spring semester. For current listings, please see BANNER.

APMA 2820A. A Tutorial on Particle Methods

APMA 2820B. Advanced Topics in Information Theory
The theory of large deviations attempts to estimate the probability of rare events and identify the most likely way they happen. The course will begin with a review of the general framework, standard techniques (change-of-measure, subadditivity, etc.), and elementary examples (e.g., Sanov's and Cramer's Theorems). We then will cover large deviations for diffusion processes and the Wentsel-Freidlin theory. The last part of the course will be one or two related topics, possibly drawn from (but not limited to) risk-sensitive control; weak convergence methods; Hamilton-Jacobi-Bellman equations; Monte Carlo methods. Prerequisites: AM 263 and 264.

APMA 2820C. Computational Electromagnetics

APMA 2820D. Conventional, Real and Quantum Computing with Applications to Factoring and Root Finding

APMA 2820E. Geophysical Fluid Dynamics

APMA 2820F. Information Theory and Networks

APMA 2820G. Information Theory, Statistics and Probability

APMA 2820H. Kinetic Theory
We will focus on two main topics in mathematical study of the kinetic theory: (1) The new goal method to study the trend to Maxwellians; (2) various hydrodynamical (fluids) limits to Euler and Navier-Stokes equations. Main emphasis will be on the ideas behind proofs, but not on technical details.

APMA 2820I. Multiscale Methods and Computer Vision
Course will address some basic multiscale computational methods such as: multigrid solvers for physical systems, including both geometric and algebraic multigrid, fast integral transforms of various kinds (including a fast Radon transform), and fast inverse integral transforms. Basic problems in computer vision such as global contour detection and their completion over gaps, image segmentation for textural images and perceptual grouping tasks in general will be explained in more details.

APMA 2820J. Numerical Linear Algebra
Solving large systems of linear equations: The course will use the text of Treften and Bao that includes all the modern concepts of solving linear questions.

APMA 2820K. Numerical Solution of Ordinary Differential Equations

We discuss the construction and general theory of multistep and multistage methods for numerically solving systems of ODE's, including stiff and nonlinear problems. Different notions to stability and error estimation and control. As time permits we shall discuss more advanced topics such as order reduction, general linear and additive methods, symplectic methods, and methods for DAE. Prerequisites: AM 219 and AM 255 or equivalent. Some programming experience is expected.

APMA 2820L. Random Processes in Mechanics

APMA 2820M. Singularities in Elliptic Problems and their Treatment by High-Order Finite Element Methods
Singular solutions for elliptic problems (elasticity and heat transfer) are discussed. These may arise around corners in 2-D and along edges and vertices in 3-D domains. Derivation of singular solutions, characterized by eigenpairs and generalized stress/flux intensity factors (GSIF/GFIFs) are a major engineering importance (because of failure initiation and propagation). High-order FE methods are introduced, and special algorithms for extracting eigenpairs and GSIF/GFIFs are studied (Steklov, dual-function, ERR method, and others).

APMA 2820O. The Mathematics of Shape with Applications to Computer Vision
Methods of representing shape, the geometry of the space of shapes, warping and matching of shapes, and some applications to problems in computer vision and medical imaging. Prerequisite: See instructor for prerequisites.

APMA 2820P. Foundations in Statistical Inference in Molecular Biology
In molecular biology, inferences in high dimensions with missing data are common. A conceptual framework for Bayesian and frequentist inferences in this setting include: sequence alignment, RNA secondary structure prediction, database search, and tiled arrays. Statistical topics: parameter estimation, hypothesis testing, recursions, and characterization of posterior spaces. This is a core course in proposed Ph.D. program in computational molecular biology.

APMA 2820Q. Topics in Kinetic Theory
This course will introduce current mathematical study for Boltzmann equation and Vlasov equation. We will study large time behavior and hydrodynamic limits for Boltzmann theory and instabilities in the Vlasov theory. Graduate PDE course is required.

APMA 2820R. Structure Theory of Control Systems
The course deals with the following problems: Given a family of control systems S and a family of control systems S', when does there exist an appropriate embedding of S into S'? Most of the course with deal with families of linear control systems. Knowledge of control theory and mathematical sophistication are required.

APMA 282S. Topics in Differential Equations
A sequel to AM 221 concentrating on similar material.

APMA 2020T. Foundations in Statistical Inference in Molecular Biology
In molecular biology, inferences in high dimensions with missing data are common. A conceptual framework for Bayesian and frequentist inferences in this setting including: sequence alignment. RNA secondary structure prediction, database search, and tiled arrays. Statistical topics: parameter estimation, hypothesis testing, recursions, and characterization of posterior spaces. Core course in proposed PhD program in computational molecular biology.

APMA 2820U. Structure Theory of Control Systems
The course deals with the following problems: given a family of control systems S and a family of control systems S', when does there exist an appropriate embedding of S into S'? Most of the course will deal with the families of linear control systems. Knowledge of control theory and mathematical sophistication are required.

APMA 2820V. Progress in the Theory of Shock Waves
The course will begin with a self-contained introduction to the theory of "hyperbolic conservation laws," that is quasilinear first order systems of partial differential equations whose solutions spontaneously develop singularities that propagate as shock waves. Then a number of recent developments will be discussed. The aim is to familiarize the students with the current status of the theory as well as with the ever expanding areas of applications of the subject.

APMA 2820W. An introduction to the Theory of Large Deviations
The theory of large deviations attempts to estimate the probability of rare events and identify the most likely way they happen. The course will begin with a review of the general framework, standard techniques (change-of-measure, subadditivity, etc.), and elementary examples (e.g., Sanov's and Cramer's Theorems). We then will cover large deviations for diffusion processes and the Wentsel-Freidlin theory. The last part of the course will be one or two related topics, possibly drawn from (but not limited to) risk-sensitive control; weak convergence methods; Hamilton-Jacobi-Bellman equations; Monte Carlo methods. Prerequisites: APMA 2630 and APMA 2640.

APMA 2820X. Boundary Conditions for Hyperbolic Systems: Numerical and Far Field

APMA 2820Y. Approaches to Problem Solving in Applied Mathematics

APMA 2820Z. Topics in Discontinuous Galerkin Methods
In molecular biology, inferences in high dimensions with missing data are common. A conceptual framework for Bayesian and frequentist inferences in this setting including:

sequence alignment. RNA secondary structure prediction, database search, and tiled arrays. Statistical topics: parameter estimation, hypothesis testing, recursions, and characterization of posterior spaces. Core course in proposed PhD program in computational molecular biology.

APMA 2821A. Parallel Scientific Computing: Algorithms and Tools

APMA 2821D. Random Processes and Random Variables.

APMA 2970. Preliminary Examination Preparation

APMA 2980. Research in Applied Mathematics

APMA 2990. Thesis Preparation

LIBRARY AND COMPUTER FACILITIES

Situated near the Division, the 14-story Sciences Library holds an extensively vast store of scholarly reference and research materials, and provides a wide range of services which support study and research in the field of Applied Mathematics. The Division offers excellent computing facilities and support on both the departmental and university levels. Located only a block away, The Watson Center for Information Technology (CIT) is the center of Brown's computing facilities. Housing many computer workstations and clusters, it offers a help desk with expert consultants. The Center for Computational and Visualization houses parallel Linux computing clusters, and also maintains an Immersive Virtual Reality display, a "Cave," for scientific visualization and graphics research. Data storage facilities include a parallel filesystem with 40 terabytes of RAID disk and a 1 petabyte tape library. These core computing and data facilities are integrated with the Division's desktop networks and the campus backbone network through Gigabit Ethernet routing switches. The Division desktop environment is a mix of Intel-architecture PCs and workstations running the Windows and Linux operating systems. The University maintains a broad range of campus-licensed software, including compilers, numerical libraries, mathematical problem-solving environments, visualization software, statistical packages and productivity software. Applied Mathematics students now enjoy a newly renovated computing/teaching facility located in 180 George Street. Tutorial and study sessions as well as small classes find an ideal setting which provides not only a comfortable and relaxed atmosphere but state-of-the-art audio/visual and computer equipment. Another recent acquisition for the Division of Applied Mathematics is a modern video conferencing system which is housed in a fully outfitted seminar room. This equipment permits teleconferenced classes and collaboration, which is especially beneficial in facilitating the Division’s strong partnership with Paris VI.

INFORMATION FOR APPLICANTS

Applications

On-line application is preferred, via the web site:

https://apply.embark.com/Grad/Brown/66/

Or, if you would rather use a paper application, you can request one to be sent to you by mail at: http://inquiry.embark.com/brown/grad/ .

Or, if web access is inconvenient, you can request an application form via e-mail by sending your name, mailing address, e-mail address and intended area of study to: Admission_Graduate@brown.edu . (Do not send resume or other information with this request.)

Finally, you can also request an application by writing to the Graduate School at:

Graduate School
Brown University
P.O. Box 1867
Providence, RI 02912, USA

For answers to specific questions, prospective students should write to:

Chair, Graduate Committee
Division of Applied Mathematics
Brown University
P.O. Box F
Providence, RI 02912.

The Internet address for information about the Division of Applied Mathematics is dam@dam.brown.edu. For more detailed information about the Division's Graduate Program, please visit our website at http://www.dam.brown.edu/graduate/ .

Prospective applicants who are interested in visiting the campus and meeting with a faculty member to discuss the graduate and research programs should contact the Chair of the Graduate Committee or the Senior Graduate Program Coordinator of the Division at telephone number (401) 863-2463.

Required Exams

The GRE (Graduate Records Examination) General Test is required, unless it is actually impossible for the test to be taken. Most applicants take a GRE subject test in some area of Mathematics, Science, or Engineering. While this test is not required, it is recommended. Foreign students are required to have a grade of at least 500 on the TOEFL (Test of English as a Foreign Language) examination for admission and higher scores are expected for financial aid.

Financial Aid

The Division of Applied Mathematics offers several forms of financial aid to cover the tuition and living expenses of qualified graduate students. These include fellowships, teaching and research assistantships.

There are also some special fellowships with a slightly higher stipend for qualified students working in certain areas supported by special federal programs. Most first-year students are supported by fellowships. Summer support can usually be arranged for students who are working on research projects. **Applications for fellowships for the 2010-11 academic year are due January 4th, 2010.**

Graduate students in good standing and making good progress in their work are normally supported during their full period of study, if the time required is within the norm, or otherwise under special circumstances. Usually four years are required for the completion of the work for a Ph.D. for students without prior graduate training. The financial awards are competitive with those of other institutions, and the cost of living in Providence is lower than that in the larger metropolitan areas. Students do not normally participate in teaching or research during their first year, so that they can concentrate on their studies. Typically, students will participate in some teaching activity later in their stay.

Housing

There are rooms in Miller Hall, and numerous apartments are available in the vicinity of the University on the East Side of Providence.

Providence and Environs

Brown University is situated on College Hill on the East Side of Providence. This area has a deep historical heritage and has preserved many fine buildings which date from the late 1700s or early 1800s, as well as some from an earlier time. Some of these buildings are part of the Brown University campus. There are numerous cultural activities at Brown and at the Rhode Island School of Design, a well-known school of art and design, as well as at theaters in Providence. Part of the interest of the area is its great ethnic diversity. Providence is less than an hour's drive from Newport, a popular tourist destination offering historical attractions, recreation and entertainment. Boston is also nearby and offers a wealth of cultural and educational attractions. The State of Rhode Island boasts many fine beaches and many other recreational facilities.