Graduate Program
Division of Applied Mathematics
Brown University

Handbook

Updated December 11, 2009

Introduction

This handbook is intended to give our graduate students an overview of the graduate program in the Division of Applied Mathematics at Brown University, and to answer some of the commonly raised questions in policies and procedures. Faculty may also find it helpful in providing information about the graduate program.

The information contained in this handbook will aid our graduate students in navigating the course that graduate study and degree completion entail. Please keep it handy and refer to it often. Many of the questions and concerns that graduate students will have in the weeks and months ahead are addressed here. In the years ahead, all will engage in much hard work as we pursue important mathematical problems and seek to expand our knowledge. Our departmental community greatly values scholarship, but we strive to provide an atmosphere conducive to personal as well as professional growth. We hope that all our graduate students will find themselves comfortable and enjoy their graduate study. If any student should find that this is not the case, he/she is encouraged to discuss with any appropriate faculty member his/her concerns or feelings about the best course of action. Open communication keeps small problems from growing into large ones, and keeps us on track towards achieving our objectives.

We will continue to keep this handbook updated, and welcome comments or suggestions. Please send comments and suggestions either to the Graduate Program Chair, Professor Constantine Dafermos, or to the Senior Graduate Program Coordinator, Jean Radican.

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.

Faculty and Staff

We enclose here a list of faculty and their areas of research, and a list of our staff. The Division strives to maintain an informal, friendly, and helpful atmosphere for our graduate students. Please always ask our faculty or staff when you have any questions. They will do their best to help you.

Generally, if you have any questions of an administrative nature, please see our Senior Graduate Program Coordinator Jean Radican. She will either help you herself or refer you to another appropriate staff member. For more detailed information about faculty research, refer to the home pages of individual faculty, or talk to them directly. Office location, telephone numbers and e-mail addresses of faculty, staff, visitors and graduate students can be found within our website, www.dam.brown.edu .

List of faculty and their research areas

Elie Bienenstock, Associate Professor of Applied Mathematics of Applied Mathematics and Neuroscience. Theoretical neuroscience, artificial vision.

Frederic E. Bisshopp, Professor Emeritus of Applied Mathematics. Asymptotics, nonlinear wave propagation, fluid mechanics.

Constantine M. Dafermos, Professor of Applied Mathematics, Alumni-Alumnae University Professor and Chair of the Graduate Program. Continuum mechanics, differential equations.

Philip J. Davis, Professor Emeritus of Applied Mathematics. Numerical analysis, approximation theory.

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.

Paul G. Dupuis, Chair and Professor of Applied Mathematics. Stochastic control, probability theory.

Peter L. Falb, Professor Emeritus of Applied Mathematics. Control, stability theory.

Wendell H. Fleming, Professor Emeritus of Applied Mathematics and Mathematics. Stochastic differential equations, stochastic control theory.

Walter F. Freiberger, Professor Emeritus of Applied Mathematics and Medical Science, and Chair of the Executive Committee of the Center for Statistical Sciences. Statistics, biostatistics.

Stuart A. Geman, Professor of Applied Mathematics, and James Manning Professor. Probability and statistics, natural and computer vision.

Basilis Gidas, Professor of Applied Mathematics. Applied probability and statistics, computer vision, image and speech recognition.

Ulf Grenander, Professor Emeritus of Applied Mathematics. Probability and statistics, pattern theory.

Yan Guo, Professor of Applied Mathematics. Partial differential equations, Kinetic theory.

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 non-smooth domains.

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, perception organization.

Jan Hesthaven, Associate Chair and Professor of Applied Mathematics. Numerical analysis, spectral high-order methods, scientific computing, computational electromagnetics, optics, and fluid dynamics.

Din-Yu Hsieh, Professor Emeritus of Applied Mathematics. Fluid mechanics, mathematical physics.

George Em Karniadakis, Professor of Applied Mathematics. Computational fluid dynamics, scientific computing, turbulence modeling.

Harold J. Kushner, Professor Emeritus of Applied Mathematics and Engineering, and L. Herbert Ballou University Professor. Stochastic control and stability, operations research.

Charles Lawrence, Professor of Applied Mathematics. Computational molecular biology.

John Mallet-Paret, Professor of Applied Mathematics. Differential equations, dynamical systems.

Martin Maxey, Professor of Applied Mathematics and Engineering, and Director of the Center for Fluid Mechanics. Turbulence and Computation. Dynamics of two-phase flow, turbulence, turbulent mixing, dispersion of particles or bubbles.

Donald E. McClure, Professor Emeritus of Applied Mathematics. Pattern analysis, image processing, mathematical statistics.

Govind Menon, Associate Professor of Applied Mathematics and Chair, Undergraduate Committee. Dynamical systems, partial differential equations, materials science.

David Mumford, University Professor of Applied Mathematics (Emeritus). Pattern theory, biological and computer vision.

Boris Rozovsky, Professor of Applied Mathematics**.** Stochastic processes and random fields, in particular stochastic partial differential equations and stochastic fluid dynamics. Nonlinear filtering and target tracking, stochastic numerics, statistics of stochastic processes, mathematical modeling of high speed computer networks, financial mathematics.

Björn Sandstede, Professor of Applied Mathematics. Applied dynamical systems and partial differential equations, dynamics of patterns, coherent structures, and nonlinear waves.

Chi-Wang Shu, Professor of Applied Mathematics. Numerical analysis, scientific computing, computational physics.

Lawrence Sirovich, Professor Emeritus of Applied Mathematics. Gas-dynamics, perturbation methods, mathematical biology.

Walter Strauss, Professor of Mathematics and Applied Mathematics, and L. Herbert Ballou University Professor. Nonlinear waves, scattering theory, partial differential equations.

Chau-Hsing Su, Professor of Applied Mathematics. Fluid mechanics, mathematical physics.

Hui Wang, Associate Professor of Applied Mathematics. Stochastic analysis and optimization, mathematical and computational finance, Monte Carlo simulation.

Staff

Madeline Brewster, Administrative Assistant

Janice D'Amico, Administrative Coordinator

Camille O. Dickson, Executive Officer

Stephanie Han, Departmental Computer Coordinator and Senior Editorial Assistant

Laura Leddy, Assistant Financial and Operations Administrator

Jean Radican, Senior Graduate Program Coordinator

Roselyn Winterbottom, Coordinating Technical Secretary

Jie Zhang, Systems Manager

Address, Telephone, Fax

The mailing address of the Division is:

Division of Applied Mathematics
Brown University
182 George Street
Providence, RI 02912 USA

You may substitute ``Box F" for Division of Applied Mathematics (or put both). The street address "182 George Street"' is important for deliveries other than the US Postal Service (for example, for Federal Express and UPS). The main telephone for the Division is (401) 863-2353, and the fax number is (401) 863-1355.

Academic Advising

Every graduate student has a faculty advisor at all times during his/her graduate study in the Division. For Ph.D. students who have not yet passed the preliminary exams they are assigned a temporary Academic Advisor. Ph.D. students who have passed the preliminary exams, a Thesis Advisor is assigned. The Graduate Chair is also a source of advising for all graduate students.

Graduate Chair

The Graduate Chair is the Chair of the Division's Graduate Program Committee. He/She is also the Graduate Representative of the Division to the Graduate School. The Graduate Chair oversees many internal academic affairs of the Division's graduate program. He/She signs most departmental permission forms and is available to advise graduate students on a variety of academic matters at individual meetings. You are encouraged to consult with the Graduate Chair on any appropriate matter. The current Graduate Chair is Professor Yan Guo.

Senior Graduate Program Coordinator

The Senior Graduate Program Coordinator performs most of the routine administrative work of our graduate program. You should check with the Senior Graduate Program Coordinator if you have any questions of an administrative or procedural nature. The current Senior Graduate Program Coordinator is Jean Radican.

Academic Advisor

At the time of initial enrollment for graduate study, a student will be assigned, by the Graduate Chair, an Academic Advisor who is a member of the Division's faculty (usually a member of the Graduate Program Committee). We will pass out a form in which you can fill in your initial and tentative research interest, and the assignment of your Academic Advisor is based on this stated interest. You may also suggest a specific faculty member as your Academic Advisor. Note that the initial and tentative research interest may and often does change after the student takes the first year of courses. The Academic Advisor discusses with the student the choice of courses (for Sc.M. and Ph.D. students), and discusses with the student the preparation for the preliminary exams, as well as possible future thesis research areas (for Ph.D. students). The Academic Advisor also approves any changes (add or drop) of courses during the semester. Course registration cards should be signed by the Academic Advisor or by the Chair of the Graduate Program Committee before the student passes the preliminary exams.

It is emphasized that an Academic Advisor is distinct from a Thesis Advisor. There is no obligation on the part of the student or the Academic Advisor to continue working together for thesis research.

Thesis Advisor

Also called Research Advisor, a Thesis Advisor is the main guidance for Ph.D. thesis research. The Thesis Advisor can be a faculty member from the Division or from another department. The student should consult with his/her Academic Advisor and the Graduate Chair if he/she plans to choose a Thesis Advisor from another department. We encourage our students to consider possible research areas and Thesis Advisors early, but they should not commit themselves with haste. The Division's philosophy and funding structure is such that students with initial fellowship support are under no pressure to determine a tentative Thesis Advisor until the end of the first semester in their second year. When choosing a Thesis Advisor, the student should consider foremost whether the research subject is what he/she likes the most and has a good

background in. If the student is interested in several research areas or professors, he/she should feel free to talk to all of the relevant faculty members to get a feeling about a complete picture. It can also be very useful for a student to talk to other students to help in the choice of an advisor.

We encourage students to actively search for a Thesis Advisor no later than the first semester in their second year. After a student has found and decided on a potential Thesis Advisor, he/she should discuss with the potential Thesis Advisor the preliminary exam topics and possible research subjects. The potential Thesis Advisor usually serves as the Chair of the preliminary exam committee and also as one of the examiners for the major subject. Only after the student successfully passes the preliminary exams will the Thesis Advisor become official. **A student must find a Thesis Advisor no later than one month after he/she passes the preliminary exam in order to be considered for support in the following year.** Course registration cards should be signed by the Thesis Advisor or by the Chair of the Graduate Program Committee after the student passes the preliminary exams.

Occasionally, a student may find it necessary to change a Thesis Advisor. There are no restrictions on doing this, but the student should discuss the matter with both the old and the new Thesis Advisor, and with the Graduate Chair, before making such a change.

Courses and Grades

In the first one or two years of graduate study, the main effort of most of our graduate students is directed toward taking courses. Students also take courses after their preliminary exams, with the advice of their Thesis Advisors.

One question which is asked often is: Are grades important? Grades are obviously a factor in evaluating overall student performance, particularly in the first year, and we generally expect our students to do well in coursework. We do realize, however, that there are variations in grades among different courses or even for the same course with different instructors. We consider all factors in the performance of students' coursework during the yearly evaluation of students.

Brown University offers all students the option of taking courses on a Satisfactory/No Credit basis. This practice is generally not appropriate for graduate students in our Division and is therefore strongly discouraged. No courses taken with a SAT/NC option can count towards an Sc.M. degree. If a student is considering taking courses under the SAT/NC option, he/she should first discuss the matter with his/her Academic Advisor or Thesis Advisor.

Permission to drop courses: It sometimes occurs that a course is not as appropriate as initially expected. It may make sense to drop such a course and apply efforts elsewhere. However, it is departmental policy that no course may be dropped without first obtaining permission from the Academic Advisor, the Thesis Advisor, or the Graduate Chair.

Choice of courses

Course requirements for advanced degrees in applied mathematics are flexible. There are no predetermined general departmental requirements. The Academic Advisor or the Thesis Advisor

makes an effort to discuss with the student the design of a course selection which fulfills the needs and satisfies the interests of the student, as well as prepares him/her for the thesis research if he/she is a Ph.D. student.

There are, however, traditional patterns which most new graduate students follow when designing their course programs with their Academic Advisor. These patterns of courses are determined by the ways in which various graduate courses are interrelated, and by the areas in which students often concentrate their studies. The purpose of this section is to describe common and recommended patterns for first-year course programs. These remarks are aimed primarily at Ph.D. students. Candidates for the Sc.M. degree may adopt programs which differ slightly from the standard ones described here; the differences will depend on the extent to which personal professional goals take precedence in determining an individual program.

During the new student orientation in early September, faculty members from each research group will describe relevant courses and make suggestions on how students should choose courses if they wish to work in the research area.

In planning their course programs, Ph.D. students should keep the preliminary examination requirements in mind. The prelims are based largely on course work done in the first one or two years.

The standard full-time load is four courses each semester. Teaching assistants and research assistants take a maximum of three courses each semester. A common and recommended program for the first year of four courses per semester includes two out of the three course sequences from the following list of ``General Basic Courses," a one-year course in the student's most probable major area, and a one-year course in an area that is distinct from the preceding one and that is either a possible major area or a minor area for the purpose of the preliminary examination.

General basic courses

These general basic courses are taken mostly by our first- or second-year students and are offered every year.

Applied Mathematics 2050-2060 is a preparation course sequence for the basis of applied mathematics, mainly for engineering students. Students with strong mathematics background do not need to take it. The sequence APMA 2050-2060 may not be used as a preliminary exam topic.

Applied Mathematics 2110-2120 is a basic analysis sequence which provides required background for several other courses on differential equations, control theory, numerical analysis and probability, in particular for APMA 2190-2200, 2230-2240, 2630-2640, 2550-2560, and 2570. Most of the graduate students take this sequence, and use it either as a major or as a minor subject in their preliminary exams. Besides providing a necessary background for many other courses, this sequence is also a good opportunity to encounter fundamental mathematical techniques and ideas.

Applied Mathematics 2130-2140 is the basic sequence in analytical methods of applied mathematics, specifically partial differential equations and integral equations. The background provided by this sequence is taken for granted in higher level courses in PDE's, mechanics, numerical analysis, probability and mathematical statistics, and other branches of analysis. This sequence can be used in the preliminary exams as a topic in Applied Mathematics Methods, but only as a minor subject.

Courses in various research areas

We can group, loosely, other graduate courses into various research areas. However, this grouping is somewhat artificial, as many courses are applicable to different research areas. Some courses are not offered every year or may have a different course description, so please check the on-line Course Announcement (BANNER).

The descriptions below express the core elements of each individual course. The course descriptions in the BANNER listings may vary from year to year, depending upon the emphasis taught by individual faculty members.

Analysis and differential equations

Students in analysis, ordinary and partial differential equations, and dynamical systems often take courses in this group to use as topics for the major in their preliminary exams. Students in other areas of research also often take these courses with the advice of their Academic Advisor or Thesis Advisor, sometimes to use them as topics for either the major or the minor in their preliminary exams.

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 Applied Mathematics 2140.

APMA 2170.

Functional Analysis and Applications. Linear spaces, metric spaces, operators, contraction principle, fixed point theorems, linear functionals, adjoint spaces, spectral theory. Non-linear operators. Special spaces, and selected applications to differential equations, control theory, integral equations, quantum mechanics, and numerical analysis.

APMA 2190 - APMA 2200.

Nonlinear Dynamical Systems: Theory and Applications. Basic theory of dynamical systems, phase portraits, Poincaré-Bendixson Theorem, stability and attraction, invariant manifolds, bifurcation theory, nonlinear oscillations, method of averaging, chaotic behavior.

APMA 2210.

Topics in Dynamical Systems. Topics of interest in dynamical systems and ordinary, partial and functional differential equations.

APMA 2230 - APMA 2240.

Partial Differential Equations. This sequence is also cross listed as Mathematics 2370-2380 and is taught by the faculty either from the Division of Applied Mathematics or from the Department of Mathematics. Distributions, Fourier transforms and Sobolev spaces. The Cauchy problem. Hilbert space methods, Elliptic boundary problems and regularity. Hyperbolic and parabolic systems. Semester I covers the basic linear theory. Semester II focuses on some special topic, usually nonlinear.

Mechanics

Students in mechanics and computational fluid dynamics often take courses in this group to use as topics for the major in their preliminary exams. Students in other areas of research also often take these courses with the advice of their Academic Advisor or Thesis Advisor, sometimes to use them as topics for either the major or the minor in their preliminary exams.

APMA 2350.

Advanced Elasticity. This course is cross listed as Engineering 2270 and is taught by an engineering faculty member. Large elastic deformations. Controllable deformations of incompressible materials. Initial stress problems. Elastic stability. Additional topics may include membrane theory, fiber-reinforced material, second-order elasticity.

APMA 2360.

Topics in Continuum Mechanics. This course is cross listed as Engineering 2280 and is taught by an engineering faculty member. 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. This course is cross listed as Engineering 229 and is taught by an engineering faculty member. 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 problems, uniqueness. Upper and lower bound theorems of limit analysis and shakedown. Slip line theory.

APMA 2380.

Stress Waves in Solids. This course is cross listed as Engineering 2260 and is taught by an engineering faculty member. Interested students should register for Engineering 2260.

APMA 2390.

Viscoelasticity. This course is cross listed as Engineering 2250 and is taught by an engineering faculty member. Interested students should register for Engineering 2260.

APMA 2410.

Fluid Dynamics I. This course is cross listed as Engineering 2810 and is taught by a faculty member either from the Division of Applied Mathematics or from the Division of Engineering. Tensor notation. Thermodynamics. Eulerian and Lagrangian description of fluid motion. Conservation laws. Constitutive relations and irreversible processes. Initial and boundary conditions. Vorticity and Bernoulli theorems. Potential flow in two and three dimensions. Surface waves in a liquid.

APMA 2420.

Fluid Dynamics II. This course is cross listed as Engineering 2820 and is taught by a faculty member either from the Division of Applied Mathematics or from the Division of Engineering. Dimensional analysis and similarity. Classification of flows according to dimensionless ratios. Exact, incompressible, viscous flow. Stokes and Oseen approximations and Stokes' formula. Boundary layer theory of the Blasius problem; hydrodynamic stability; inviscid theories; the Orr-Sommerfeld equation; qualitative theory of viscous instabilities. Turbulence. Compressible flow. Simple waves and shock waves. Sound propagation.

APMA 2470 - APMA 2480.

Topics in Fluid Dynamics. Topics chosen from: Rarefied gas dynamics; Hydromagnetics; Non-Newtonian fluids; Stability Theory; Turbulence. Numerical analysis and scientific computing

Students in numerical analysis and scientific computing often take courses in this group to use as topics for the major in their preliminary exams. Students in other areas of research also often take these courses with the advice of their Academic Advisor or Thesis Advisor, sometimes to use them as topics for either the major or the minor in their preliminary exams.

APMA 2550.

Numerical Solutions of Partial Differential Equations I. Numerical techniques for the solution of time-dependent partial differential equations of mathematical physics. The course includes both theory and applications. Knowledge of computer programming is required.

APMA 2560.

Numerical Solutions of Partial Differential Equations II. Special Topics: boundary conditions, spectral methods, numerical solutions of non-linear hyperbolic differential equations, approximation theory and applications of functional analysis, finite element method. Topics may vary from year to year. Students are allowed to take it more than once with the permission of the instructor when the topics are different.

APMA 2570.

Numerical Solutions of Partial Differential Equations III. Special Topics: finite element method, shock wave calculations, numerical linear algebra, spectral methods, parallel

computing. Topics may vary from year to year. Students are allowed to take it more than once with the permission of the instructor when the topics are different.

APMA 2580.
Numerical Solutions of Partial Differential Equations IV. Computational fluid dynamics

Probability, statistics and stochastic control

Students in probability, statistics, bio-statistics, stochastic control, image processing and computer vision often take courses in this group to use as topics for the major in their preliminary exams. Students in other areas of research also often take these courses with the advice of their Academic Advisor or Thesis Advisor, sometimes to use them as topics for either the major or the minor in their preliminary exams. In addition to the courses below, students interested in applied statistics may wish to take courses offered by the Center for Statistical Sciences and Community Health (Biostatistics).

APMA 2260.
Introduction to Stochastic Control Theory. Topics of current interest in the control of stochastic systems.

APMA 2630 - APMA 2640.
Theory of Probability. This sequence is also cross listed as Mathematics 2630-2640 and is taught by the faculty either from the Division of Applied Mathematics or from the Department of Mathematics. 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. Topics in the theory of continuous parameter stochastic processes. The precise content varies from year to year, but generally includes many of the following topics: second order stationary processes, ergodic processes and their applications. Markov processes including jump processes and diffusions, applications to noise and communication theory. Prerequisite: APMA 2640.

APMA 2670.
Mathematical Statistics I (Statistical Inference). This course presents a comprehensive account of the theoretical aspects of modern statistical methods. Topics include: exponential families, sufficiency and completeness, frequentist point and interval

estimation, unbiasedness, maximum likelihood estimation and large sample methods, Bayesian inference, hypothesis testing, and non-parametric inference. Recent advances in computational approaches will also be discussed. Prerequisites: Background in multivariate calculus and introductory probability theory.

APMA 2680.

Mathematical Statistics II. Introduction to decision and game theories; admissibility; complete class theorems; the Bayesian approach to statistics; subjective and prior information; posterior distribution; Bayesian methods for point estimation, hypothesis testing, and multiple decision problems; Bayesian sequential analysis; the sequential likelihood tests; applications to classification and learning problems. Prerequisite: APMA 2670.

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.

Advanced seminar courses

APMA 2810 and APMA 2820, Seminars in Applied Mathematics, are seminar courses with topics varying from year to year. Please refer to the current on-line course announcement (BANNER)

Courses in other departments

There are many courses in other departments, such as in computer science, engineering, geology, mathematics, neuroscience and physics, which are suitable for our graduate students to take. These courses are either related to the research or applicable as a minor subject in the preliminary exams, or both. Please check the current on-line course announcement (BANNER) and discuss with your Academic Advisor or Thesis Advisor the suitability of any such courses.

Undergraduate courses

Occasionally there are undergraduate (1000 level) courses which may be suitable for our graduate students. Please check the current on-line course announcement (BANNER) and discuss with your Academic Advisor or Thesis Advisor the suitability of any such courses.

Advanced Degree Requirements

The Graduate School of the University gives considerable latitude to individual departments in supplementing University-wide requirements for advanced degrees. The Division has adopted the following requirements, to which (rare) exceptions can only be made by the Graduate Program Committee.

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.

Doctoral candidacy

To become a Ph.D. candidate it is necessary to pass a preliminary oral examination. The preliminary examination may be taken at most twice. A student who has passed the preliminary examination must find a Thesis Advisor within one month, in order to be considered for financial support for the following academic year.

Preliminary exam

The preliminary exam is the main exam all Ph.D. students must take before formally being admitted to doctoral candidacy and starting thesis research. The purpose of this exam is to allow the faculty to assess whether the student has the breadth and depth of background necessary for Ph.D. thesis research.

The preliminary exam is an oral exam of four hours in total length. There is a major area with two topics and two minor areas each with one topic. Each topic will be examined for one hour. The exam is administered by an examination committee which consists of four faculty members, one for each topic. The major topics are covered in one session of about two hours duration, and the minors in another two-hour session. The two parts of the examination must take place within a two-week period. Rare exceptions to this timing can only be made by the Graduate Chair and then only for reasons of scheduling difficulties or unusual circumstances.

Graduate students generally take the preliminary examination between the end of their first year and the end of their second year of graduate studies. The preliminary examination committee usually consists of the student's potential Thesis Advisor as Chair and three other faculty members. Applications to take the preliminary examination can be obtained through the Graduate Program Coordinator.

The proposed topics and examiners for the preliminary examination are prepared in consultation with and approved by the potential Thesis Advisor or another faculty member who agrees to be the Chair of the examination committee. The student then should contact the three other proposed examiners to get their approval, and submit the proposal to the Graduate Chair for approval. The candidate is encouraged to formulate the proposal well in advance of the examination, but in any case it must be presented to the Graduate Chair at least three months before the expected date of the examination. The proposed program should include the names of potential examiners.

In order for the proposed program to be approved by the Graduate Chair, the examination should satisfy certain minimum requirements. At least one of the four areas must be designated as an applied area. In the applied area, most of the questioning will concern the scientific or engineering aspects of the subject. At least one of the four areas must qualify as a theoretical area, in which the examination will concentrate on mathematics of that area. At least one of the minor areas must not be closely related to the major area. Each major area should cover the equivalent of at least one year of course work. Associated with each minor should be the equivalent of at least one year of course work, although the questioning can focus on a one-semester course. The major areas may be based on two different aspects of the same subject-area, such as theoretical and applied fluids or theoretical and computational numerical methods, but each part must be represented by a separate faculty member. In any case, the major areas should present a unified body of material that is viewed by the Graduate Chair and the examiners as the main areas needed for the student to conduct research in his/her chosen field. The topics should be chosen from among the following:

1. Analysis or Mathematical Methods (methods can be a minor only).

2. PDE's or ODE's/Dynamical Systems.

3. Probability, Statistics, and Stochastic Processes.

4. Control Theory (stochastic or deterministic) and Operations Research.

5. Numerical Analysis and Scientific Computation.

6. Fluid and Solid Mechanics.

7. Outside minor from a department such as Biology, Computer Science, Economics, Engineering, Mathematics or Physics.

Additional topics not listed here can also be proposed, subject to the approval of the Graduate Chair.

The examiners may in some cases give the candidates written questions in addition to the oral examination.

The preliminary examination integrates a large amount of material in a more mature way than is possible in standard course work. It provides an opportunity for the faculty to see whether the student has the breadth and depth of background necessary for Ph.D. research. While the material covered in the examination is normally taken from course work, the examiners might ask new questions on the basic material or questions that integrate topics from several course areas.

In most cases the Chair of the preliminary exam committee continues to serve as the Thesis Advisor after the student passes the exam. If this is not the case, the student must find a Thesis Advisor within one month after passing the preliminary exam in order to be considered for support for the following academic year.

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 requirement for the Ph.D. degree includes the equivalent of three years of full-time study (i.e. twenty-four tuition units) beyond the bachelor's degree. For students with graduate course credits from other universities, a maximum of eight semester courses (worth eight tuition units) can be transferred. We encourage such students to talk to their Academic Advisor or Thesis Advisor, or to the Graduate Chair about the suitability of such transfer of credits.

Sometime after passing the Preliminary Examination and before the final thesis defense, the Ph.D. Thesis Advisory Committee is formed by the student in consultation with his/her Ph.D. Thesis Advisor. The Committee is composed of the Ph.D. Thesis Advisor as Chair and two other faculty members, who will be readers of the thesis. We encourage an early formation of this committee in order to facilitate discussions and interactions between the student and the two committee members other than the Chair. Application forms for the Ph.D. can be obtained through the Graduate Program Coordinator. Completed forms must be submitted at least three weeks prior to the defense date.

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 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 Certification Programs, Individual Consultation Services (including teaching, presentation, course, syllabus and grant consultations), the Teaching Seminar Lectures & Forums, and a wide variety of online handbooks and workshops. For more information, please see the Sheridan Center's website.

The degree candidate must write a dissertation which contains results of original research and gives evidence of high scholarship.

The degree candidate shall present a public expository talk on the content of the dissertation.

Following the expository talk, there will be an oral final examination on the content and details of the dissertation. The final exam is conducted by the Ph.D. Thesis Advisory Committee and is open to the faculty of the Division of Applied Mathematics.

The thesis must be filed by May 1 in order to obtain the degree in that academic year.

Teaching

Teaching is one important component in the training of Ph.D. students. Communication skills are now emphasized not only in academia but also in other work places. Teaching is an excellent opportunity to improve communication skills. Every Ph.D. student must perform at least one year's teaching as a TA (teaching assistant).

A TA performs 20 hours of teaching duties for undergraduate or occasionally beginning graduate courses. The specific duties vary from course to course, but the minimum involves four hours of combined recitation sessions and office hours. A significant amount of time for the TA's is spent in preparing the course material, either by attending the lectures or by reading the textbook and

handouts, before doing the recitation sessions and holding office hours. In addition, TA's may be asked to grade homework and exams. For some courses, TA's will be assigned a grader to help grade homework. Nevertheless, *the preparation of answer keys is the responsibility of the TA* and not the grader.

A TA will be asked to fill out a form choosing up to three preferred courses. Every effort is made by the Graduate Chair to match the interest of TA's with our instructional needs. But TA's must be prepared to be assigned to any of our undergraduate course.

The University maintains many resources for the training of teaching assistants. One such resource is the Sheridan Center. The Graduate Program Coordinator will periodically pass information on such resources to our graduate students, who are encouraged to use them to improve their teaching ability.

Certification of students whose native language is not English

According to University policy, any foreign graduate student whose native language is not English must be certified by the Office of English for International Teaching Assistants as competent in oral English before being assigned to teach. If the evaluation reveals a need for supplementary training in oral English, the office of English for International Teaching Assistants will help the student choose the most effective method to achieve competency. The University and Division agree it is imperative that TA's be able to effectively convey course material in understandable English. As a Division policy, we require our first-year graduate students whose first language is not English to take this evaluation and exam by this office no later than the end of their first semester. Information about this evaluation and exam can be obtained through the Graduate Program Coordinator. If a student fails this evaluation, he/she will be required to take an English class in the second semester and take the evaluation exam again at the end of the second semester. A student may jeopardize his/her financial support if he/she does not pass this evaluation before the beginning of the second year of graduate study.

Evaluations and Financial Support

Student evaluations

At the beginning of each calendar year, usually in January, the Division faculty meets to review the performance and accomplishments of each student, including any teaching activities. Students are ranked according to their academic performance.

Financial support

For students who are accepted with university fellowship support, a total of five years of support is guaranteed. During the second and subsequent years, those with initial guaranteed support, will typically receive a TA, RA, or dissertation fellowship.

It is the policy of the Division to give summer support, usually in the form of an RAship, to all graduate students who have financial support in the preceding academic year and who plan to stay on campus and request summer support. The amount of summer support varies each year due to the availability of funding. In recent years we have been supporting students between 2 and 2.5 months during the summer.

Other Issues

We include in this section other issues which are important to graduate students.

Academic honesty

Cheating and other forms of dishonesty are not tolerated by the Division or the University. Dismissal and/or a permanent notation on departmental records are possible actions in clear-cut and serious cases of dishonesty. Faculty, teaching assistants, and all graduate students must be vigilant to circumstances where academic honesty are being or have been compromised.

Computer resources

There is an advanced computing facility in the Division consisting of networked workstations, PC's and printers. Every student will be given an account on this system. See Stephanie Han (182 George, Room 213) for setting up your account. Your Academic Advisor or Thesis Advisor may be asked to pay on your behalf for this service out of grants when you are performing research related to the grants. Information about our computer resources can be found at http://www.dam.brown.edu/computing/**.** You may also visit Brown's Computing and Information Services site at http://www.brown.edu/Facilities/CIS/index.php .

There is also a University account for each student. To activate, please visit http://activate.brown.edu/files/activate/ . Information is also contained in the package you receive when you first enroll.

Enrollment fee and dissertation filing fee

Once a student has paid for 24 tuition units, he or she is still responsible for an enrollment fee.

A student who has completed a thesis while away from Brown, either on leave of absence or as a traveling scholar, must either re-enroll *or* pay a dissertation filing fee before he or she submits their thesis. Obviously, the filing fee is more desirable -- the relevant fee depends upon timing, and the student should consult the Dissertation Coordinator in the Graduate School (Barbara Bennett). However, students who need access to the library, computers, or other facilities must re-enroll and pay tuition or the enrollment fee.

All students must pay a "thesis fee" before they can receive the Ph.D. degree, and need to submit a clearance from the Bursar's office.

Grievance procedure

Students should usually bring concerns or grievances directly to the attention of an advisor or instructor. If the outcome of this informal process is unsatisfactory, or if a student does not want to approach the advisor or instructor directly, he/she may bring the matter to the Graduate Chair, who will work with the student and faculty member toward a resolution. Beyond this, the University provides formal grievance procedures, which can be found in the Graduate School Student Handbook.

Leaves of absence

Leaves of Absence are granted for a variety of professional, educational, medical, psychological and personal reasons. They are granted for one semester or for one year, and may be extended to two years if necessary. Students on leave do not have library or athletic facility privileges unless they are alumni of the school or pay a fee (inquire at the Rockefeller Library Circulation desk).

Loans

Federal loans are available through the government. For more information, please visit: www.financialaid.brown.edu

Office space

Every full-time Ph.D. student is assigned a desk in a shared office for graduate students. If you are not satisfied with your office location, you may sign your name with Laura Leddy in Room 113 to be in the queue for reassignment (this can be done at any time). The order of the queue is strictly according to seniority (the date when candidacy is obtained, or the date when the preliminary exam is passed, or the date of entering the program). Those students who have fulfilled both requirements for admission to Ph.D. candidacy (that is, passed their prelim and fulfilled the foreign language reading requirement) will always have first choice as space becomes available. After those students have received their assignments, the other students who have requested space will be considered, depending upon their status. The more requirements they have fulfilled, the better are their chances of obtaining an office. When an office space is open, the first one in the queue will be given the option to move. If he/she does not want this space, he/she can skip this one and stay in the queue, while the option to move will be given to the next student in the queue, etc.

Part-Time Study

With the approval of the Graduate Chair, you may study for a degree on a part-time basis.

Payroll

Students are on a semi-monthly payroll. For any payroll problems please see Jean Radican in Room 128 promptly. For tax deduction questions, please visit the payroll office located on the 2nd floor of the Brown Office Building.

Photocopying and Telephones

Incoming graduate students are given a user code for the copier. They pay $.05/page and are billed monthly. Please see Laura Leddy in Room 113 for the assignment of a user code for the copier.

There are phones in all office areas. Students can make local and campus calls, but there are no long distance phone privileges. A student needs to get a long distance calling plan (i.e., a calling card from the phone company) in order to make calls from an office.

Re-admission

If you are seeking re-admission after medical or psychological leave, your doctor must write to the appropriate person in Health Services or Psychological Services and confirm your ability to resume your studies. Financial aid issues and remaining degree requirements are best discussed with the Graduate Chair. If you wish to be re-admitted, you must inform the Graduate School in writing no later than one month prior to the semester of anticipated return.

Second Master's degree

Doctoral students may earn a second Master's degree from Brown, in a related field, without an additional charge for tuition. No courses or theses, however, will count toward more than one Master's degree. Please see the Senior Graduate Program Coordinator Jean Radican for the appropriate form.

Related University services

We list here several University services which have been found useful to our graduate students.

Brown Computing and Information Services

For information provided by Brown's Computing and Information Services, visit their website. CIS also provides a host of training seminars and workshops to acquaint students and faculty with the newest software applications and other topics of interest relating to computer technology.

C**atalogue of the University**

The University Catalogue is published every few years and contains very general information about degree requirements and courses in all departments at Brown. It lists

courses that are regularly taught throughout the University, though the on-line Course Announcement (BANNER) provides the most accurate listing of current course offerings.

Course Announcement Bulletin

The bulletin is distributed every spring just before pre-registration for the fall term. It contains course listings, schedules, and an academic calendar for the following year. This is what you will consult before you register. If you don't already have a copy, you can pick one up in the main office, in Room 113. The BANNER version is a more updated listing of course offerings.

Brown University Directory

The University directory lists the phone numbers and addresses for all students and all departments at Brown. The Directory is updated every year and is usually available in November in the main office in Room 113. An electronic address book is found at http://www.brown.edu/web/directory/ .

Health Fee

The University Health Services fee is paid for by the University for appointments such as fellowships, TA and RA appointments. This is not health insurance.

Health Insurance

If a student is supported by an appointment from the University (i.e., fellowship, TA or RA appointments) their health insurance is automatically covered by the University. However, those students who are self-supported have the option to purchase health insurance from Brown University

International House of Rhode Island

This is not actually a Brown service, but is affiliated with the University. They run the Brown International Student Orientation, take new foreign students shopping for essentials, run a host family program, as well as other programs throughout the year. If you are interesting in obtaining their services you may call 421-7181, or visit their website: http://mysite.verizon.net/vze72o2y/

Job Placement

There is a Career Planning Office (http://careerdevelopment.brown.edu/) on campus which has information about jobs and recruitment activities. Your Thesis Advisor is usually the first source of job searching when you are ready to graduate. You may ask for recommendation letters from your Thesis Advisor and other faculty members.

Library Publications

A number of useful publications on library resources and services at Brown are found at http://www.brown.edu/Facilities/University_Library/ . Note also that many journals are available on line.

Taxes

All students should file W-4 forms with the University Payroll Office to avoid penalties. Stipends for teaching assistantships or research assistantships are subject to income tax and withholding. Fellowship stipends are paid with no withholding, but are subject to federal income tax. Foreign students should check with the Director of Foreign Students, Elke Breker, at ext. 3-2427, as they may be exempt from tax payments in this country due to tax agreements their country may have with the USA. Check your tax status annually with the Foreign Student and Faculty Office (usually in January) to maintain your tax exempt status if applicable.

For other related questions or general information, visit the Foreign Student and Faculty site at http://www.brown.edu/Administration/Foreign_Student_Office/ .