Division of Applied Mathematics

Guide to Undergraduate Programs

Revised November 2009

Introduction

This short guide is intended to give students and faculty an overview of the undergraduate program in Applied Mathematics at Brown University, and to answer some of the commonly raised questions. Applied Mathematics is an interdisciplinary subject involving both mathematics and many areas of application. More so than in many other areas it is important to have an overview of the subject and how it relates to other programs at Brown. Many students come to Brown with little prior understanding about what Applied Mathematics is or the broad range of opportunities that it provides.

The Division first prepared this guide in 1991, and has been updating it since then. Many people have said that they have found it valuable. We will continue to keep it up to date and improve it, and welcome comments or suggestions.

Applied Mathematics at Brown

What is Applied Mathematics?

Applied Mathematics is an inherently interdisciplinary subject which covers a wide spectrum of scientific activities. It is the mathematics of problems arising in the physical, life and social sciences as well as in engineering, and provides a broad qualitative and quantitative background for use in these fields. The methods of mathematical modeling and analysis provide a unification and mutual enrichment of ideas from many different areas, and a deeper understanding of the fields to which it is applied. Applied Mathematics draws concepts and methods of mathematics to the fields of application and, in turn, brings ideas, techniques and scientific knowledge back to influence the development of mathematics.

Owing to its nature, Applied Mathematics appeals to people with a variety of different interests, ranging from those with a desire to obtain a good quantitative background for use in some future career, to those who wish to have a better understanding of the basic mathematical aspects of other fields, or to those who are interested in the basic techniques and approaches in themselves. Many of the students in Applied Mathematics courses like mathematics and want to learn more about it, but do not intend to use it professionally. Others want to learn more about a subject that is becoming more and more basic to many fields. Many go on to specialize in economics, finance or the other social sciences. The curriculum of the Division is flexible enough to meet these different desires.

Some examples might help to illustrate the range of Applied Mathematics, and the interaction between applications and mathematics which is involved. The examples are sampled from interests of the faculty.

Medicine and the Environment

One surprising example arises in medicine. High frequency ventilation of the lungs is a procedure now used in surgery when the lungs of a patient must be immobilized. Oxygen supply to the lungs and the removal of carbon dioxide is achieved by small "tidal" oscillations where small amounts of air are blown in and out of the lungs very rapidly. Similar exchange and dispersal processes take place in tidal estuaries and coastal waters, and this latter problem has been studied by civil engineers for quite some time. From the point of view of mathematical modeling, the two types of processes are essentially the same and applied mathematicians working with engineers and physiologists have carried out basic developments.

Computational Vision

The next example concerns certain types of probabilistic models that have been used for some time in statistical physics. It was realized recently that the same mathematical framework could be used to model complex decision problems in computer (robotic) vision and automatic image processing. The same underlying mathematical methods have also led to major advances in computational methods for the optimization of very complex systems (such as VLSI design) and in speech recognition.

Optimization Problems in Financial Markets and Manufacturing

Some of the recent work in the study of general mathematical problems in optimal decision making under uncertainty has been used to study financial markets and investment strategies, and these in turn have further focused some of the mathematical work. The mathematics of risk analysis has led to useful models for policy decisions for parts of the health care system. Some manufacturing problems can be modeled as flows of material in networks, subject to capacity and other constraints (and possibly under some uncertainty or randomness as well). Optimal network flow theory is now a well-developed subject. Conversely, specific manufacturing models have often led to new demands on the mathematics. New types of materials composed of laminates and composites have unusual and highly desirable properties. An understanding of their strength, reliability, electrical, optical or other properties requires a good mathematical description of the component parts and their interactions, and has in turn led to the study of new types of differential equations.

Computer Modeling and Simulation

The computer has made it possible to attack problems of a scope not dreamed of several years ago. The design of aircraft, ships and automobiles all depend on computer modeling. To do the modeling, one needs to simulate the physical laws which govern the behavior, and these laws are often defined by differential or other mathematical equations. For large problems, the required modeling is not easy to do since the computer can provide at best only an approximation, and the accumulation of small errors often leads to poor results. A major goal of numerical analysis is the design of methods that maintain accuracy even for large-scale problems. Without advances in this area, even the most powerful computers would be useless to solve complex "real life" problems.

Physical Systems, Mathematical Models and Computer Analysis

The problem of turbulence in fluids and gases gives another interesting class of examples. The problem is of major importance in engineering, and has been characterized as one of the outstanding technical challenges at this time. The needs of this problem have led to new ideas in scientific computation, differential equations and statistics. Conversely, virtually all of the mathematical areas represented in the Division have been applied to that problem. Supercomputers have been an essential tool in these investigations, and have been a stimulus for the discovery and rigorous mathematical investigation of more efficient numerical methods for use in all branches of science. They allow us to attack more complex and less idealized problems, and require different mathematical methods for their efficient utilization. The properties of the physical problem might guide the discovery of the methods, but mathematical insight is needed in such an investigation, since it involves a rigorous comparison of the behavior of the ideal model for the physical problem and the properties of the `approximate' model with which the computer actually works.

Brown University's Division of Applied Mathematics

Brown University is unusual in having a separate department devoted to Applied Mathematics. The Division of Applied Mathematics was created in 1941 in response to the awareness of the contributions that such a program could make to the dramatically increasing national scientific and engineering needs of that period. Since then the scope and interests of the Division have developed as the subject areas have evolved.

The Division of Applied Mathematics provides a special environment for the interaction of people with varied scientific interests. The Division draws together faculty who elsewhere might be dispersed in quite different departments, depending on their primary interests. In fact, Applied Mathematics programs in other Universities are often spread among several departments and lack the coherence and focus of the program at Brown.

The basic mathematical skills of Applied Mathematics come from a variety of sources, which depend on the problems of interest: the theory of ordinary and partial differential equations, matrix theory, statistical sciences, probability and decision theory, risk and insurance analysis, the classical methods for formulating and solving problems in the sciences, operational analysis, optimization theory, the mechanics of solid materials and of fluids flows, numerical analysis, scientific computation and the science of modern computer based modeling.

Courses are regularly offered in all of these areas. Each year, there are special offerings in topics of current interest, such as the mathematics and physics of systems which exhibit "chaotic" behavior, cryptography, and the mathematics of speculation.

The standard Applied Mathematics concentrations lead to either the A.B. or Sc.B. degrees. The program is very flexible. Numerous joint programs with other departments are described below, and individual concentrations suited to particular needs can be arranged. The range of offerings, either within Applied Mathematics alone, or in combination with offerings of other departments, provide almost endless opportunities.

Career Paths

Students take courses in applied mathematics for many reasons, not necessarily with an applied mathematics concentration in mind. The value of learning about applied mathematics goes beyond a career opportunity. It provides an education in the use of quantitative methods in thinking about and solving problems: knowledge that is valuable in all walks of life.

The various concentrations in Applied Mathematics do prepare students for a great variety of career opportunities. In recent years students who have followed one of the undergraduate concentrations in Applied Mathematics have gone into many different areas including: graduate study in applied mathematics, engineering, physical or earth sciences; actuarial work, insurance and investment management; computer consulting and information industries; scientific careers in industry or government service; medical school; teaching; banking and finance; graduate study in economics or business studies; operations research or statistical analysis in industry or government agencies. In particular courses offered in applied mathematics provide the preparation needed for several of the actuarial professional examinations. Business schools often seek graduate applicants with a good background in applied mathematics and economics.

Information Resources Describing Professional Opportunities

The major professional organizations in the mathematical sciences publish information about career and educational opportunities. A short list of these resources and how to access them is given below. These documents are available on the web, and the relevant URLs are included here. (The online version of this document contains active web links.)

American Mathematical Society (AMS)
201 Charles Street
P.O. Box 6248
Providence, RI 02940-6248
800 321-4267
http://www.ams.org

The AMS fosters mathematics research and its members are predominantly based in colleges and universities. It provides professional services for students and mathematical scientists.

The AMS, in cooperation with SIAM and MAA, and supported by funding from the Sloan Foundation, maintains a web site of career profiles of professionals trained in the mathematical sciences. The URL is http://www.ams.org/careers/

This database is searchable by various characteristics of the individuals included, such as their highest degree in the mathematical sciences. Check out this site.

Each fall, the AMS publishes a guide to support (assistantships, fellowships and scholarships) entitled *Assistantships and Graduate Fellowships in the Mathematical Sciences*. This is particularly useful for undergraduates considering advanced study in mathematical sciences. A copy is available at the Division for reference.

American Statistical Association (ASA)
1429 Duke Street
Alexandria, VA 22314-3402 703 684-1221
http://www.amstat.org

The ASA is the principal professional organization for statisticians in the US. The ASA publishes three brochures aimed at students who wish to learn about professions in statistics:

- *Careers in Statistics*
- *Women and Statistics*
- *Minorities in Statistics*

Single copies are available for free from the ASA, and an electronic summary of *Careers in Statistics* can be found at the link for Education on the ASA web site.

Association for Women in Mathematics (AWM)
4114 Computer and Space Sciences Building
University of Maryland
College Park, MD 20724-2461
301 405-7892
email: awm@awm-math.org
http://www.awm-math.org/

The AWM works to encourage women to study and to have active careers in the mathematical sciences. The AWM publishes two brochures of potential interest to students interested in pursuing mathematical studies:

- *Profiles of Women in Mathematics: The Emmy Noether Lectures*
- *Careers that Count: Opportunities in the Mathematical Sciences*

The former publication describes careers and accomplishments of female research mathematicians and may be of interest to students considering graduate study. It is accessible in electronic form at the link for Noether Lecture Series on the AWM web site. *Careers that Count* is available for $1.50.

Casualty Actuarial Society
Suite 600
1100 N. Glebe Road
Arlington, VA 22201 703 276-3100
http://www.casact.org

The Casualty Actuarial Society promotes actuarial science applied to property, casualty, and similar risk exposures. It administers standards for professional certification of casualty actuaries, including education programs and exams for Associates and Fellows. Their web site includes a brochure entitled *An Actuarial Career*.

Institute for Operations Research and the Management Sciences (INFORMS)
Suite 400 901 Elkridge Landing Road
Linthicum, MD 21090-2909 800 4INFORMS
http://www.informs.org

INFORMS is the primary professional organization for OR and MS, formed through the merger of the Operations Research Society of America (ORSA) and The Institute of Management Sciences (TIMS). INFORMS publishes two brochures likely to be of interest to students who wish to learn about careers in OR/MS:

- *Careers in Operations Research*
- *Educational Programs in Operations Research*

Both of these are available free from INFORMS. The INFORMS web site includes *The INFORMS Career Booklet: Is a Career in Operations Research/Management Science Right for You?* http://www.informs.org/Edu/Career/booklet.htmln . This is an interesting and well-organized resource about OR careers.

Mathematical Association of America (MAA)
1529 Eighteenth Street N.W.
Washington, DC 20036
202 387-5200
http://www.maa.org

The MAA promotes mathematics education and preparation for careers that build on mathematics. It publishes three brochures about professional opportunities in mathematical sciences:

- *Careers in the Mathematical Sciences* (free)
- *Mathematical Scientists at Work* ($3.00)
- *More Careers in the Mathematical Sciences* ($.25)

The MAA web site also includes career profiles of individuals with degrees in mathematical sciences. Visit http://www.maa.org/careers/

National Academy of Sciences / National Academy of Engineering / Institute of Medicine
http://www.nap.edu

The National Academy Press is the publisher for the National Academies and the Institute of Medicine. Its web site contains a wealth of information about science, engineering and health including reports by expert panels about directions for development of branches of mathematical sciences. One particular publication that may be of interest to students considering graduate school is *Careers in Science and Engineering: A Student Planning Guide to Grad School and Beyond*, http://www.nap.edu/readingroom/books/careers/

Society for Industrial and Applied Mathematics (SIAM)
3600 University City Science Center
Philadelphia, PA 19104-2688
215- 382-9800
http://www.siam.org

SIAM is a leading professional organization of applied mathematicians in industry and academia. It is devoted to advancing the application of mathematics to science and industry. The SIAM web site includes a continuing series of articles entitled *Mathematics That Counts* highlighting advances in applied and computational mathematics that have led to increased productivity, improvements in product design, and solutions to problems related to health and the environment. These can be accessed through the link to SIAM News from the SIAM Home Page or directly at http://www.siam.org/siamnews/mtc/mtc.htm

Society of Actuaries
Suite 800 475 North Martingale Road
Schaumberg, IL 60173-2226 708 706-3500
http://www.soa.org

The Society of Actuaries is the principal professional organization of life actuaries who (in contrast with casualty actuaries) are primarily concerned with assessment of risks in the fields of life insurance, health insurance, and pensions and annuities. The actuarial societies tout the fact that "actuary" was twice rated the best job in America by the *Jobs Rated Almanac*. The 1988 and 1995 editions put the actuarial profession at the top of the list of 250 professions ranked on criteria such as work environment, job outlook, security, and stress. The Society of Actuaries publishes the brochure, *Actuaries Make a Difference*, which is free. Its web site contains information about education programs and actuarial exams for certification as an Associate or Fellow of the Society.

Insurance Mathematics

Although not specifically designed for the purpose, some of the Division's courses offer preparation for several of the Associateship examinations of the Society of Actuaries. In particular, APMA 1650 (Introduction to Mathematical Statistics) and APMA 1660 (Linear Models) are ample preparation for the Society's examinations for its Courses 1100 (Probability and Statistics) and 1200 (Applied Statistical Methods), although the latter also contains some time series analysis covered, in much greater detail, in APMA 1670 (Time Series Analysis). The material in the Society's Courses 1300 (Operations Research) and 1350 (Numerical Methods) are more than completely covered in APMA 1200 (Operations Analysis: Probabilistic Models), APMA 1210 (Operations Analysis: Deterministic Models) and APMA 1170 (Introduction to Numerical Analysis).

Choosing Courses

The courses in Applied Mathematics are designed for students with a wide range of goals and are not limited to the needs of students following an applied mathematics concentration. There are

many opportunities for students to explore different subject areas and find which they find most interesting. In this section we list and explain the courses offered by the Division showing how they relate to each other. These courses are offered each year unless stated otherwise. We also list a selection of courses from other departments which are relevant to applied mathematics, either giving further applications or providing additional mathematical background.

When choosing courses consider what your goals are. Do you wish to pursue applied mathematics at a graduate level? Do you wish to gain a good basis in applied mathematics at an undergraduate level, but intend later to pursue some other related area? Are you simply taking courses for general understanding and knowledge?

A general recommendation for students planning to follow graduate study in any subject relating to applied mathematics (engineering, economics, physics, chemistry, computer science, etc.) is to complete the three semester calculus sequence MATH 0090,0100 and 0180 or the equivalent; and in addition to complete the linear algebra course MATH 0520 or MATH 0540. This recommendation is also sound advice for all students.

Students taking courses in applied mathematics start either with one of the lower level courses (APMA 0090 or APMA 0160) or with the Mathematical Methods courses APMA 0350, 0360 (or 0330,0340) which provide many of the basic approaches used in applied mathematics. The Statistical Inference Course APMA 1650 provides the introduction to the other courses in statistics and operations research, while APMA 1170 gives a good overview of numerical methods. Beyond these comments, students should select courses so that they pursue specific topic areas in a coherent manner.

Students following the applied mathematics concentration and intending to go on to graduate study in this subject should take some additional mathematics courses, such as those mentioned later in this section. Faculty concentration advisors will be glad to give advice on course selections to *all* students.

Courses in Applied Mathematics

Introductory Courses

APMA 0090. Introduction to Modeling
Topics of Applied Mathematics, introduced in the context of practical applications where defining the problems and understanding what kinds of solutions they can have is the central issue. Computations are performed in MATLAB; instruction is provided.

APMA 0160. Introduction to Computing Sciences
For student in any discipline that may involve numerical computations. Includes instruction for programming in MATLAB. Applications include solution of linear equations (with vectors and matrices) and nonlinear equations (by bisection, iteration, and Newton's method), interpolation, and curve-fitting, difference equations, iterated maps, numerical differentiation and integration, and differential equations. Prerequisite: MATH 0100 or its equivalent.

APMA 0180. Modeling the World with Mathematics: An Introduction for Non-Mathematicians
Mathematics is the foundation of our technological society and most of its powerful ideas are quite accessible. This course will explain some of these using historical texts and Excel. Topics include the predictive power of 'differential equations' from the planets to epidemics, oscillations and music, chaotic systems, randomness and the atomic bomb. Prerequisite: some knowledge of calculus. Further information is available at http://www.dam.brown.edu/people/mumford/AM18.

APMA 0410. Mathematical Methods in the Brain Sciences
Basic mathematical methods commonly used in the cognitive and neural sciences. Topics include: introduction to differential equations, emphasizing qualitative behavior; introduction to probability and statistics, emphasizing hypothesis testing and modern nonparametric methods; introduction to Fourier analysis. Time permitting, also considers some elementary information theory. Examples from biology, psychology, and linguistics. Prerequisite: MATH 0100 or equivalent.

APMA 0650. Essential Statistics
A first course in statistics emphasizing statistical reasoning and basic concepts. Comprehensive treatment of most commonly used statistical methods through linear regression. Elementary probability and the role of randomness. Data analysis and statistical computing using Excel. Examples and applications from the popular press and the life, social and physical sciences. No mathematical prerequisites beyond high school algebra.

Mathematical Methods

The courses APMA 0330/0350 and APMA 0340/0360 cover mathematical techniques involving differential equations used in the analysis of physical, biological and economic phenomena. In the sequence APMA 0330, 0340 the primary emphasis is placed on the use of established methods rather than on rigorous treatment of the underlying mathematics. APMA 0350, 0360 covers similar material (except for introduction to statistics) in more depth. It is intended for students who prefer a more rigorous development of the mathematical foundations of the methods.

Students who are considering one of the concentrations in Applied Mathematics and others who will be taking advanced courses in Applied Mathematics, Mathematics, Physics or Engineering are encouraged to take APMA 0350, 0360.

APMA 0330/0350. Methods of Applied Mathematics I
Solution of first order differential equations, including the use of exact differentials. Solution of second order, linear differential equations. Laplace transform methods. Numerical methods for solving ordinary differential equations.

APMA 0340/0360. Methods of Applied Mathematics II
Review of vector algebra and matrix methods, with applications to systems of linear, first order differential equations. Nonlinear problems and stability. Introduction to partial differential

equations and Fourier series methods. Boundary value problems and an introduction to Sturm-Liouville systems. **Note:** APMA 0340 also contains a short introduction to probability/statistics.

Prerequisites: MATH 0090, 0100. It will be expected that most students taking APMA 0330, 0340 and all students taking APMA 0350, 0360 will have taken MATH 0180 (or equivalent) or will be taking it at the same time. Students are strongly encouraged to take MATH 0520 or MATH 0540 (Linear algebra). The majority of students in APMA 0350, 0360 have taken or are taking a linear algebra course.

Beyond these two basic courses in mathematical methods, the Division offers a third course APMA1330 that covers partial differential equations and their applications. More general problems and specific methods of solution will be discussed, together with a more detailed coverage of topics such as Fourier series and Fourier transforms. The course will be of immediate relevance to students interested in applications to the physical sciences, engineering and biology.

APMA 1330. Methods of Applied Mathematics III
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.

Biological Systems

There are many applications of mathematics to the description and quantitative study of biological processes. Applied mathematics provides many valuable tools in determining the relative importance of the many factors that may affect biological systems in such diverse areas as population studies, epidemiology, chemical oscillators and the nervous system. Students interested in developing a concentration combining biology and applied mathematics should contact Professor David Rand in Biology, or Professor Elie Bienenstock in Applied Mathematics.

The course APMA 1070 (BIOL 1490) listed below is suitable for students who may not be specialists in biology but have some background in the subject, and are interested in some of the applications of mathematics in the biological sciences. There are also interested related courses in biomechanics offered in Engineering (ENGN 1210, 1220).

APMA 1070. Quantitative Models of Biological Systems (BIOL 1490)
An introductory course on the use of quantitative modeling techniques in solving problems in biology. Each year one major biological area will be explored in detail from a modeling perspective. The particular topic will vary from year to year. Mathematical techniques will be discussed as they arise in the context of biological problems. Prerequisites: some introductory level biology; APMA 0330, 0340 or 0350, 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.

Numerical Analysis and Scientific Computation

The course APMA 1170 is a valuable, general introduction to numerical methods that are widely used in many applications. It provides an essential basis for scientific computation, whatever the area of interest. APMA 1180 is more specifically focused on ordinary and partial differential equations. This would be of value to students with interests in applications to the physical sciences or engineering.

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, not required.

APMA 1180. Introduction to the Numerical Solution of 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.

Operations Analysis

Operations Analysis originated with attempts to make optimal decisions about the allocation of scarce resources, the design of efficient distribution networks and the need to make rational, optimal decisions when faced with uncertain information. The field has grown now to include many of the mathematical methods and models which are used for the design, optimization and analysis of management systems in government, business and economics.

Two courses which cover the fundamental ideas and methods of the field are offered: Applied Mathematics 1200 is concerned with probabilistic or statistical models, where the system of concern is subject to randomness or uncertainty of some sort. It is an excellent introduction to some of the most widely used models and ideas of probability theory as well as their use in practical problems; Applied Mathematics 1210 is concerned with optimization or analysis methods for deterministic problems. The courses deal with both the theory and selected applications.

Students may also be interested in the closely related course ENGN 1320 - Transportation Systems Analysis.

APMA 1200. Operational Analysis: Probabilistic Models
Methods of problem formulation and solution. Introduction to the theory of Markov chains, the probabilistic `analog' of a difference or differential equation. This is the most widely used of the probabilistic processes which evolve over time according to some statistical rule. Birth-death statistical processes and their applications. Queuing, probabilistic service and waiting line theory. Sequential decision theory via the methods of Dynamic Programming. This is the theory of optimal decisions when a sequence of decisions is to be made over time, each one affecting the situation of those that come later. Prerequisite: APMA 1650, or MATH 1610, or equivalent

APMA 1210. Operational Analysis: Deterministic Methods
An introduction to the basic mathematical ideas and computational methods of optimization. Linear Programming: This is the theory of optimal decision making under linear constraints on resources, and may be the most widely used set of ideas in the field. Applications include decision theory in economics, transportation theory, optimal assignments, production and operations scheduling. The theory of network modeling and flows. The theory of integer programming, which constitute the ideas for decision and optimization when the decision variables are integers (e.g., number of staff to be assigned etc.). Prerequisites: An introduction to matrix calculations, such as APMA 0340 or MATH 0520.

Mechanics

Two undergraduate courses APMA 1250 (ENGN 1370) and APMA 1260 are offered in mechanics. The prerequisites for both are an introductory mechanics course such as ENGN 0040, PHYS 0050, PHYS 0070, and mathematical methods APMA 0330,0340. APMA 1250 covers the mechanics of systems of particles and rigid bodies, including motion in rotating systems. It explains the advanced methods used to study complex systems, and gives an understanding of the unusual characteristics of general rigid body motion. APMA 1260 is a self-contained, one semester course providing an introduction to the mechanics of fluid motion and the elasticity of solids. The course differs from traditional engineering courses in this area and will emphasize other applications to physics, earth sciences, biomechanics, and other sciences.

Beyond these courses students may also consider courses in Engineering or Geological Sciences which are listed later in this guide, or some of the first-year graduate courses offered in Applied Mathematics or Engineering on mechanics, fluid dynamics and solid mechanics.

Mechanics provides a rich supply of examples of chaotic dynamical systems, which are discussed in the course on Chaotic Dynamics (APMA 1360). This is an exciting area which is continuing to develop.

Dynamical Systems

The presence of motion in deterministic systems that is effectively unpredictable is now recognized as an essential scientific phenomenon, and modern science is slowly coming to terms

with its implications. This so-called "chaos" has challenged mathematicians and there is now a substantial mathematical theory supporting the observations of chaotic behavior in the real world. Despite its recent surge in popularity, an early motivation was the study by Poincare and others at the end of the last century of celestial mechanics. Here supposedly simple systems governed by well-defined equations of motion appeared to have very complex behavior and to be very sensitive to disturbances. As techniques of mathematical modeling have developed for new, more varied applications in economics, biology and chemistry so too has the realization that complex behavior is a common feature of nonlinear systems. The course APMA 1360 presents in a systematic way the mathematical concepts and definitions used in the study of nonlinear systems.

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: APMA 0340 or 0360, or MATH 1110; MATH 0520 or 0540.

Statistics: Theory and Applications

Probability and statistics are basic tools in economics, physics, biological modeling, many modern applications of computers (such as to image analysis, speech recognition, and expert systems), epidemiology, and in many industrial applications, such as quality control, factory automation, optimal resource allocation, and risk assessment. The sequence APMA 1650/01660 provides an introduction to the general theory. Other courses, requiring AM 1650 (or MATH 1610) as prerequisites, explore some of the more modern and more powerful statistical tools and some applications. These include APMA 1670 (Time Series Analysis), APMA 1680 (Nonparametric Statistics), APMA 1770 (Information Theory), APMA 1200 (Operations Research: Probabilistic Models), and various "Senior Seminar Courses" (listed under APMA 1930 or APMA 1940) such as Introduction to Pattern Analysis, The Mathematics of Speculation, and Information and Coding Theory.

APMA 1650. Statistical Inference I
APMA 1650/1660 constitute an integrated first course in mathematical statistics. The first half of APMA 1650 is probability theory, 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, large and small sample techniques for confidence intervals and hypothesis testing. Prerequisite: Mathematics 0100 or 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. Time Series Analysis
An introduction to stochastic processes - the study of structure and randomness in sequences of observations. Time series analysis is used to model complex interactions among evolving observations in diverse applications, such as Economics (market prices, economic indicators), Biology (nerve cell activities), Engineering (speech and other sound waveforms). Time series models are a mixture of deterministic and random components, which capture structure and fluctuations respectively. The course will cover basic classes of models and some of their applications, parameter estimation, and spectral (Fourier) analysis. Prerequisite: APMA 1660.

APMA 1680. Non-parametric Statistics
A systematic treatment of the distribution-free alternatives to classical statistical tests. These nonparametric tests make minimum assumptions about distributions governing the generation of observations, yet are of nearly equal power as the classical alternatives. Prerequisite: APMA 1650 or equivalent.

APMA 1690. Introduction to 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, estimation and hypothesis testing. Prerequisites: Linear algebra and Applied Mathematics 1650 or equivalent. Some experience in programming is desirable. Offered in alternate years

APMA 1710. 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.

Senior Seminar Courses

Each year the Division offers about two to four senior seminar courses (APMA 1930 and APMA 1940), which explore areas of applied mathematics in a manner different from the regular lecture format. Students are encouraged to study more independently and develop specific projects.

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 APMA 1650 or APMA 1610. 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: APMA 0330, 0350, 0360.

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: APMA 0110 and APMA 0340 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 APMA 1650 or APMA 1610.

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: APMA 0340 or 0360, MATH 0180 or 0200 or 0350, and PHYS 0060 or PHYS 0080 or ENGN 0510.

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 1950, APMA1960. Independent Study

APMA 1970. Independent Study

Courses in Other Departments

Applied Mathematics is an interdisciplinary subject, as noted earlier, and there are many courses taught in other departments at Brown which are relevant to an applied mathematics program, either in providing additional mathematical tools or in developing applications in one of the sciences or engineering. Listed below are some suggested courses that complement those offered by the Division, and which students may consider taking. The list is by no means comprehensive. It is meant to suggest possible directions to explore.

Many of these courses would be accepted as part of an applied mathematics concentration program. Students should ensure first that they have satisfied the prerequisites for a particular course.

Mathematics

All Applied Mathematics majors should complete the calculus sequence MATH 0090, 0100, 0180 or the equivalent, and a course in linear algebra, MATH 0520 or 0540. A student considering a graduate applied mathematics program in the future should go beyond this and take some additional courses from the Mathematics Department.

Suggestions include:

MATH 1010 Analysis

MATH 1260 Complex Analysis

MATH 1530 Abstract Algebra

These and other courses in Mathematics are accepted for the Applied Mathematics concentration.

Physics

The Physics Department offers several introductory courses such as PHYS 0050, 0060 or the more advanced PHYS 0070, 0080. These are suitable for first year students and provide an excellent background in the physical sciences and a good basis for other courses.

Suggested courses include:

PHYS 0050 Foundations of Mechanics

PHYS 0060 Foundations of Electromagnetism and Modern Physics

PHYS 0070 Analytical Mechanics

PHYS 0080 Physics of Waves, Relativity and Quantum Mechanics

PHYS 0470 Electricity and Magnetism

PHYS 1510 Advanced Electromagnetic Theory

PHYS 0500 Advanced Classical Mechanics

PHYS 0790 Physics of Matter

Other courses are relevant as applications areas in applied mathematics but are directed more towards students following a concentration in physics.

Engineering

The structure of courses in Engineering is directed towards students following an accredited engineering program. However, it is 0050,0060 or the equivalent as preparation.

Suggested courses include:

ENGN 0520	Electrical and Optical Systems
ENGN 1570	Linear Systems Analysis
ENGN 1580	Communication Systems
ENGN 1630	Digital Electronics Systems Design
ENGN 1660	Automatic Control Systems
ENGN 0310	Mechanics of Solids and Structures
ENGN 1750	Advanced Mechanics of Solids
ENGN 0720	Thermodynamics
ENGN 0810	Fluid Mechanics
ENGN 1860	Advanced Fluid Mechanics
ENGN 1210	Biomechanics
ENGN 1220	Neuroengineering Control of Movement

Cognitive and Linguistic Sciences

COGS 0410	Introduction to Linguistic Theory
COGS 1020	Neural Modeling Laboratory
COGS 1290	Understanding the Brain

Chemistry

The Chemistry Department offers a variety of courses on introductory chemistry, chemical kinetics, inorganic and organic chemistry that are valuable for their general scientific content.

CHEM 0100	Introductory Chemistry
CHEM 0330	Equilibrium, Rate and Structure

At the 1000-level, more advanced courses offered include:

CHEM 1140	Physical Chemistry: Quantum Chemistry
CHEM1150	Physical Chemistry: Thermodynamics and Statistical Mechanics

Geological Sciences

GEOL 1350	Meteorological Aspects of Climatic Change
GEOL 1600	Environmental and Exploration Geophysics
GEOL 1610	Solid Earth Geophysics
GEOL 1620	Continuum Physics of the Solid Earth
GEOL 1960	Groundwater Penetrating Radar Data Analysis

Computer Science

There is a standard concentration in Applied Mathematics - Computer Sciences for the Sc.B. degree which lists specific course suggestions.

Economics

There are standard concentrations in Applied Mathematics - Economics for both the Sc.B. and A.B. degrees which list specific course suggestions.

Biology

We have already mentioned the connections between applied mathematics and the study of biological systems. Students interested in combining studies in Biology and Applied Mathematics should consult a concentration advisor about structuring an independent concentration.

There are two graduate level courses in Biology and Medicine – Community Health that are suitable for students who have taken statistics courses in Applied Mathematics and are interested in public health issues.

PHP 2510	Principles of Biostatistics and Data Analysis
PHP 2511	Applied Regression Analysis

Standard Concentrations

Applied Mathematics offers several standard concentration programs which are listed in detail in the University Catalogue and the Course Announcement. Both the A.B. and Sc.B. concentrations in Applied Mathematics require certain basic courses to be taken, but beyond this there is a great deal of flexibility as to which areas of application are pursued. Students are encouraged to take courses in applied mathematics, mathematics and one or more of the application areas in the natural sciences, social sciences or engineering. Whichever areas are chosen these should be studied in some depth.

Applied Mathematics Program - Standard program for the A.B. degree

Prerequisite: MATH 0090, 0100 or their equivalent.

Program: Ten additional semester courses approved by the Division of Applied Mathematics, including MATH 0180, 0520, APMA 0350, 0360 and one of APMA 0090, 0160, or CSCI 0040, 0150, or 0170. APMA 0330, 0340 will sometimes be accepted as substitutes for APMA 0350, 0360. Of the unspecified courses four should be chosen from the 100-level courses taught by the Division of Applied Mathematics. Substitution of alternate courses for the specific requirements is subject to approval of the division. Concentrators are urged to consider MATH 0540 as an alternative to MATH 0520 and to complete their introductory programming course before the end of their sophomore year.

Applied Mathematics Program - Standard program for the Sc.B. degree

Eighteen approved semester courses in mathematics, applied mathematics, engineering, the natural or social sciences, including MATH 0090, 0100, 0180, 0520; APMA 0350, 0360, and 1930 or 1940, and one of APMA 0090, 0160, or CSCI 0040, 0150, or 0170. APMA 0330, 0340 will sometimes be accepted as substitutes for APMA 0350, 0360. Of the unspecified courses six should be chosen from the 100-level or higher level courses. Substitution of alternate courses for the specific requirements is subject to approval by the division. Concentrators are urged to consider MATH 0540 as an alternative to MATH 0520 and to complete their introductory programming course before the end of their sophomore year.

Applied Mathematic - Biology - Standard program for the Sc.B. degree

The Applied Math - Biology concentration recognizes that mathematics is essential to address many modern biological problems in the post genome era. Specifically, high throughput technologies have rendered vast new biological data sets including the human genome sequence and many other post-genome data sets. These technologies have spawning a new "data-driven" paradigm in the biological sciences and the fields of bioinformatics and systems biology. The foundations of these new fields are inherently mathematical, with a focus on probability, statistical inference, and systems dynamics. These mathematical methods apply very broadly in many biological fields including some like population growth, spread of disease, that predate the genomics revolution, but their application in areas like molecular, cellular, genetics and evolutionary biology has grown very rapidly in the post genome era.

Required coursework in this program aims at ensuring expertise in mathematical and statistical sciences, and their application in biology. The students will focus in particular areas of biology. The program culminates in a senior capstone experience that pairs student and faculty in creative research collaborations. Applied Math - Biology concentrators are prepared for careers in medicine, public health, industry and academic research.

Requirements:

1. APMA 0350, 0360 (or 0330, 0340), 1650, and another approved 1000-level course.

2. Four biology courses agreed upon by the student and advisor (see below for some possible areas of emphasis).

3. MATH 0090, 0100 (or 0170), 0180, and 0520 (or an applied algebra course).

4. CHEM 0330. Recommended for some concentrators: organic chemistry and biochemistry.

5. PHYS 0030, 0040 (or 0050, 0060).

6. Two additional courses in applied math, biology, chemistry, math, or physics. *At least one of these must be a directed research course* (e.g., APMA 1930, 1940; BIOL 1950, 1960).

Possible areas of emphasis and suggested courses include:

1. Biochemistry: BIOL 0280, 1270, and CHEM 0340, 0350, 0360.

2. Cells, tissues, and organs: BIOL 0800, 1170, 1100, and/or appropriate bioengineering courses, such as BIOL 1080, 1090, 1120, 1140.

3. Neurosciences: NEUR courses; APMA 0410

4. Population biology and ecology: BIOL 0410, 0420, 0430, 0450, 0480, 1410, 1420, 1430, and other courses with permission.

5. Genetics: BIOL 0470, 1410.

Concentration Advisors

Professor David Rand, 3-1063 Walter Hall 202 or BioMed Center 418.

Professor Elie Bienenstock, 3-1195, 302D Metcalf Chemistry Laboratory.

Applied Mathematics - Computer Science – Standard Sc.B. Concentration

The standard Sc.B. concentration in Applied Math-Computer Science is designed to provide a foundation of basic concepts and methodology of mathematical analysis and computation and to prepare students for advanced work in computer science, applied mathematics, and scientific computation. Interested students may contact advisors in the Division of Applied Mathematics or the Department of Computer Science. The concentration has the following specific requirements. Prerequisites: Mathematics 0100 or 0170.

Required courses

MATH 0180 or 0350 and 0520 or 0540 (CSCI 0530 may be used as a substitute); APMA 0350, 0360, and either APMA 1170 or 1180; CSCI 0150, or 0170, 0160, or 0180, 0220, 0310, and 0320. (In some cases, substitutions of equivalent courses will be permitted.) In addition, students must complete three courses in applied mathematics at the 1000-level or higher and three 1000-level courses in computer science, as well as a senior seminar in either department. Concentrators must also complete an approved English writing course.

Of the 1000-level or higher applied mathematics courses, at least two should constitute a standard sequence, or address a common theme. For example, either of the pairs APMA 1200-1210 or APMA 1650-1660 would be suitable. Similarly, at least two of the three additional 1000-level computer science courses must constitute an approved sequence, as in the computer science A.B. concentration. In addition, at least one of the three 1000-level computer science courses must be a theoretical computer science course. Substitution of courses in mathematics or engineering for courses in applied mathematics or computer science may be permitted, at the discretion of the concentration advisor.

Applied Mathematics-Economics Concentration

The philosophy of this program is to provide sufficient command of mathematical concepts to allow pursuit of an economics program emphasizing modern research problems. Economic theory has come to use more and more mathematics in recent decades, and empirical research in economics has turned to sophisticated statistical techniques. The applied mathematics-economics concentration is designed to reflect the mathematical and statistical nature of modern economic theory and empirical research. This concentration comes in two flavors, or tracks. The first is the advanced economics track, which is intended to prepare students for graduate study in economics. The second is the mathematical finance track, which is intended to prepare students for graduate study in finance, or for careers in finance or financial engineering. Both tracks of the applied mathematics-economics concentration have A.B. degree versions and Sc.B. degree versions.

STANDARD PROGRAM FOR THE A.B. DEGREE IN APPLIED MATHEMATICS-ECONOMICS – ADVANCED ECONOMICS TRACK

Prerequisites: MATH 0100, 0520. *Course Requirements*: APPLIED MATHEMATICS:
(a) APMA 0350 and 0360. One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. One course from APMA 1200, 1210. APMA 1650.

(b) One course from APMA 1200, 1210, 1660, 1670, 1680, 1690, 1700, MATH 1010. No course may be used to simultaneously satisfy (a) and (b).

ECONOMICS: ECON 1130 (or 1110 with permission), 1210, 1630; plus three other 100-level economics courses. Of the three courses, two must be chosen from the "mathematical economics" group. This group comprises ECON 1170, 1470, 1640, 1750 (old number 178), 1850, 1860, and 1870.

STANDARD PROGRAM FOR THE SC.B. DEGREE IN APPLIED MATHEMATICS-ECONOMICS – ADVANCED ECONOMICS TRACK

Prerequisites: MATH 0100, 0520. *Course Requirements*: APPLIED MATHEMATICS:

(a) APMA 0350, 0360. One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. One course from 1200, 1210. APMA 1650.

(b) Two courses from APMA 1200, 1210, 1660, 1670, 1680, 1690, 1700, MATH 1010. No course may be used to simultaneously satisfy (a) and (b).

ECONOMICS: ECON 1130 (or 1110 with permission), 1210 and 1630; plus five other 100-level economics courses. Of the five courses, three must be chosen from the "mathematical economics" group. This group comprises ECON 1170, 1470, 1640, 1750 (old number 178), 1850, 1860, and 1870.

STANDARD PROGRAM FOR THE A.B. DEGREE IN APPLIED MATHEMATICS-ECONOMICS – MATHEMATICAL FINANCE TRACK

Prerequisites: MATH 0100, 0520. *Course Requirements*: APPLIED MATHEMATICS:

(a) APMA 0350 and 0360. One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. APMA 1200. APMA 1650.

(b) One course from APMA 1180, 1330, 1660, 1670, 1680, 1690, 1700, 1720, MATH 1010. (APMA 1720 is most preferred in this list.)

ECONOMICS: ECON 1130 (or 1110 with permission), 1210, 1630; plus three other 100-level economics courses. Of the three courses, two must be chosen from the "financial economics" group, and one must be chosen from the "mathematical economics" group. The "financial economics group comprises ECON 1710, 1720, 1750 (old number 178), 1760, and 1770. The "mathematical economics" group comprises ECON 1170, 1470, 1640, 1750 (old number 178), 1850, 1860, and 1870. No course may be used to simultaneously satisfy the "financial economics" and the "mathematical economics" requirements.

STANDARD PROGRAM FOR THE SC.B. DEGREE IN APPLIED MATHEMATICS-ECONOMICS – MATHEMATICAL FINANCE TRACK

Prerequisites: MATH 0100, 0520. *Course Requirements*: APPLIED MATHEMATICS:

(c) APMA 0350 and 0360. One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. APMA 1200. APMA 1650.

(d) Two courses from APMA 1180, 1330, 1660, 1670, 1680, 1690, 1700, 1720, MATH 1010. (APMA 1720 is most preferred in this list.)

ECONOMICS: ECON 1130 (or 1110 with permission), 1210, 1630; plus five other 100-level economics courses. Of the five courses, three must be chosen from the "financial economics" group, and two must be chosen from the "mathematical economics" group. The "financial economics group comprises ECON 1710, 1720, 1750 (old number 178), 1760, and 1770. The "mathematical economics" group comprises ECON 1170, 1470, 1640, 1750 (old number 178), 1850, 1860, and 1870. No course may be used to simultaneously satisfy the "financial economics" and the "mathematical economics" requirements.

COURSE OFFERINGS FOR ECONOMICS

ECON 0110 -Principles of Economics

ECON 0180 - First Year Seminar

ECON 0180A - Economics on a Broad Canvas

ECON 0180B - The Welfare State in America

ECON 0180B - The Welfare State in America

ECON 0510 - Development and the International Economy

ECON 0710 - Financial Accounting

ECON 0780 - Political Theory and Economic Analysis

ECON 0790 - Business, Economics, Ethics

ECON 1110 - Intermediate Microeconomics

ECON 1130 - Intermediate Microeconomics (Mathematical)

ECON 1160 - Managerial Economics

ECON 1170 - Welfare Economics

ECON 1210 - Intermediate Macroeconomics

ECON 1220 - Monetary and Fiscal Policy

ECON 1310 - Labor Economics

ECON 1360 - Health Economics

ECON 1370 - Race and Inequality in the United States

ECON 1380 - Economics and the Law

ECON 1430 - Population Economics

ECON 1440 - Economic Theories of Firms

ECON 1460 - Industrial Organization

ECON 1470 - Bargaining Theory and Applications

ECON 1480 - Public Economics

ECON 1500 - Current Global Macroeconomic Challenges

ECON 1510 - Economic Development

ECON 1520 - The Economic Analysis of Institutions

ECON 1530 - Health, Hunger and the Household in Developing Countries

ECON 1540 - International Trade

ECON 1550 - International Finance

ECON 1560 - Economic Growth

ECON 1580 - Comparative Economic Systems

ECON 1590 - The Economy of China since 1949

ECON 1600 - Economics of the Middle East

ECON 1620 - Introduction to Econometrics

ECON 1630 - Econometrics I

ECON 1640 - Econometrics II

ECON 1710 - Investments I

ECON 1720 - Corporate Finance

ECON 1750 - Investments II

ECON 1759 - Data, Statistics, Finance

ECON 1760 - Financial Institutions

ECON 1770 - Fixed Income Securities

ECON 1780 - Corporate Strategy

ECON 1790 - Corporate Governance and Management

ECON 1800 - Politics and Finance

ECON 1810 - Economics and Psychology

ECON 1850 - Theory of Economic Growth

ECON 1860 - The Theory of General Equilibrium

ECON 1870 - Game Theory and Applications to Economics

ECON 1880 - Introduction to Two-Sided Matching Markets

ECON 1970 - Independent Research

ECON 1994 - Senior Thesis and Independent Research in Finance and Applied Economics

ECON 1995 - Senior Thesis and Independent Research in Finance and Applied Economics

Sample Concentrations

Students concentrating in Applied Mathematics are able to emphasize particular areas of interest in the mathematical sciences. Standard joint concentrations focus on Biology, Computer Science or Economics. In addition, one of several themes can emerge from within a "straight" Applied Mathematics concentration (Sc.B. or A.B.).

Below are some guidelines for an Applied Mathematics concentrator who might wish to emphasize either the general area of probability/statistics/operations research, or the general area of scientific computing.

Guidelines for Applied Mathematics concentrator emphasizing probability, statistics, and operations research

The theories of probability, statistics, and operations research are increasingly exploited in modern applications, including problems in medicine (data analysis, medical imaging, epidemiology), economics (pricing and portfolio theories), robotics (machine vision, control theory), biology (genetic codes, theory of evolution, theories about the nervous system), and the actuarial sciences. An Sc.B. can be designed within the Applied Mathematics concentration that develops a basic set of tools in the theories of probability, statistics, and operations research, and explores selected applications.

Sample Program

Required:

MATH 0090, 0100, 0180 (calculus)

MATH 0520 (linear algebra) - MATH 0540 is preferable

APMA 0350, 0360 (methods of applied mathematics I, II) - or, possibly, APMA 0330, 0340

APMA 0090 (introduction to modeling), or 0160 (introduction to computing sciences), or CSCI 0040 (introduction to computing), or 0150 (computer programming, problem solving and applications).

Suggested:

APMA0900 or 0160 (topics in scientific computing). We strongly suggest students to take one course no later than in the sophomore year

APMA 1170 (introduction to numerical analysis) and 1180 (introduction to numerical solution of differential equations)

A selection of two to three courses from: APMA 1210 (operations research: deterministic models), 2050 (mathematical methods of applied sciences), 2060 (mathematical methods of applied science), 1650 (introduction to mathematical statistics)

A selection of two Senior Seminars courses (APMA 1930 or 1940). Recent examples of interest include:

Theory of difference equations
Coding and information theory
Software for mathematical experiments
Mathematics of speculation
Topics in parallel computing

Related courses in other fields---selection of two to four from engineering, computer science, mathematics and physics. Students should check with concentration advisors about suitable courses.

Honors Program

Students in the Applied Mathematics concentration (or in a joint concentration), whose work in the field of the concentration has demonstrated superior quality and culminated in an Honors Thesis of Distinction, will be recommended by the Division to be designated "Honors" upon their graduation by the University.

The GPA in the concentration courses of an honors candidate should be at least 3.6. Exceptions may be made if the GPA is marginal but the record shows an improvement over the years. The honors thesis should be supervised by a faculty member in the Applied Mathematics Division, or from another department as long as the thesis is related to Applied Mathematics, and should be seen and evaluated by another faculty member. Since the work to prepare a thesis involves at least a semester, we strongly recommend students who have the intention to apply for honors to approach a faculty member for supervising a thesis no later than the end of their third year. In April of their fourth year, the faculty member who supervises the thesis and another faculty member who has seen and evaluated the thesis must write a recommendation letter to the Applied Mathematics Division. The Division will evaluate the overall academic record including the quality of the thesis to reach a decision on whether or not to recommend to the University an honors designation.

The Rohn Truell Premium Prize

From time to time the Rohn Truell Premium Prize is awarded to outstanding students graduating in the Applied Mathematics concentration. The prize is named after Professor Truell, a former chairman and professor in Applied Mathematics.

Sigma Xi

Each year graduating students who have a strong academic record of achievement in the physical, mathematical and life sciences are considered for nomination to the Sigma Xi scientific society.

Applied Mathematics Courses to be offered in 2009-2010

Course	Semester	Course Title
APMA 0160	II	Introduction to Computing Sciences
APMA 0330	I & II	Methods of Applied Mathematics I
APMA 0340	I & II	Methods of Applied Mathematics II
APMA 0350	I	Methods of Applied Mathematics I
APMA 0360	II	Methods of Applied Mathematics II
APMA 0410	I	Mathematical Methods in the Brain Sciences
APMA 0650	II	Essential Statistics
APMA 1070	I	Quantitative Models of Biological Systems
APMA 1080	II	Inference in Genomics and Molecular Biology
APMA 1170	I	Introduction to Numerical Analysis
APMA 1200	II	Operations Research: Probabilistic Models
APMA 1210	I	Operations Research: Deterministic Models
APMA 1330	I	Methods of Applied Mathematics III
APMA1360	II	Topics in Chaotic Dynamics
APMA 1650	I	Statistical Inference I
APMA 1660	II	Statistical Inference II
APMA 1680	II	Nonparametric Statistics
APMA 1710	I	Information Theory
APMA 1950	I	Independent Study
APMA 1960	II	Independent Study

Applied Mathematics Concentration Advisors

Please see one of our undergraduate concentration advisors if you have any questions:

Professor Govind Menon (Chair)
Telephone 863-3793, Room 325
182 George Street
E-mail: menon@dam.brown.edu

Professor Charles Lawrence
Telephone 863-1479, Room 227
182 George Street
E-mail: lawrence@dam.brown.edu

Professor Boris Rozovsky
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Professor Hongjie Dong
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182 George Street
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