Undergraduate Handbook

A Guide to Undergraduate Programs

Division of Applied Mathematics, Brown University

Revised October 20, 2015
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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.

What is Applied Mathematics?

Applied Mathematics has a profound impact on our daily lives. Whether it is weather forecasts, search engines, climate research, secure online shopping, or movie recommendations, none of these would work the way they do without algorithms and tools from the mathematical sciences. More generally, 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.

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 fundamental mathematical techniques and approaches in themselves. Many students begin taking courses in the Division of Applied Mathematics and discover their favorite areas of study as they go along. The program stresses but is not limited to computing, differential equations, and applied probability which are areas of mathematics that are used most often in applications in science, society and industry. The curriculum of the Division is flexible enough to meet the goals and interests of a very wide range of students.

The basic mathematical skills of Applied Mathematics come from a variety of sources, which depend on problems from areas 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.

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.
Career Paths

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: banking, finance, and investment sector; actuarial and insurance sector; computer and software industry; consulting companies; teaching; graduate study in applied mathematics, business, economics, engineering, physical or earth sciences; scientific careers in industry or government service; medical school; 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.

If you would like to find out more about what Applied Mathematics is useful for and which types of careers people pursue with a degree in Applied Mathematics, please have a look at SIAM's career brochure at http://www.siam.org/careers/thinking/pdf/brochure.pdf or go to the career pages of the following professional societies:

<table>
<thead>
<tr>
<th>Society</th>
<th>Website</th>
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</thead>
<tbody>
<tr>
<td>American Mathematical Society (AMS)</td>
<td><a href="http://www.ams.org/profession/career-info/career-index">http://www.ams.org/profession/career-info/career-index</a></td>
</tr>
<tr>
<td>Society for Industrial and Applied Mathematics (SIAM)</td>
<td><a href="http://www.siam.org/careers/">http://www.siam.org/careers/</a></td>
</tr>
<tr>
<td>Mathematical Association of America (MAA)</td>
<td><a href="http://www.maa.org/careers/">http://www.maa.org/careers/</a></td>
</tr>
<tr>
<td>American Statistical Society (ASA)</td>
<td><a href="http://www.amstat.org/">http://www.amstat.org/</a></td>
</tr>
<tr>
<td>Association for Women in Mathematics (AWM)</td>
<td><a href="http://www.awm-math.org/">http://www.awm-math.org/</a></td>
</tr>
<tr>
<td>Institute for Operations Research and the Management Sciences (INFORMS)</td>
<td><a href="http://www.informs.org">http://www.informs.org</a></td>
</tr>
<tr>
<td>National Academy of Sciences</td>
<td><a href="http://www.nap.edu">http://www.nap.edu</a></td>
</tr>
<tr>
<td>Casualty Actuarial Society</td>
<td><a href="http://www.casact.org">http://www.casact.org</a></td>
</tr>
<tr>
<td>Society of Actuaries</td>
<td><a href="http://www.soa.org">http://www.soa.org</a></td>
</tr>
</tbody>
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Each fall, the American Mathematical Society publishes an informative online guide entitled "Assistantships and Graduate Fellowships in the Mathematical Sciences," which may be useful for undergraduates interested in pursuing a graduate degree in the mathematical sciences.

Applied Mathematics at Brown

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.

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, provides almost endless opportunities.

**Frequently Asked Questions**

A list of frequently asked questions (and answers) about our undergraduate program can be found on the Division’s website at [http://www.brown.edu/academics/applied-mathematics/undergraduate-program/frequently-asked-questions](http://www.brown.edu/academics/applied-mathematics/undergraduate-program/frequently-asked-questions).
Choosing Courses

Introduction

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 see which they find most interesting. At the end of this undergraduate guide, we list and explain the courses offered by the Division and a selection of courses from other departments that are relevant to applied mathematics by either giving further applications or providing additional mathematical background. In the present section, we discuss a few general guidelines and recommendations for choosing courses.

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.

Roadmap

The following two pages contain a roadmap for choosing courses and explain in particular some of the prerequisites that determine the order in which courses should be taken, including a new class for freshmen entitled, “Introduction to Modeling.” (APMA0200).
Roadmap to Choosing Courses (Explanation of Prerequisites)

Courses Intended for Non-Majors:
APMA 0180, 0410, 0650

Courses to Fulfill the Programming Concentration Requirement
APMA 0090, 0160, CSCI 0040, 0150, 0170, 0200

Prerequisites:
Most courses in the Division of Applied Mathematics require MATH 0090 and 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 MATH 0350 (or equivalent). Although some students will be taking this course at the same time, it is not recommended. Students are strongly encouraged to take MATH 0520 or 0540 (Linear Algebra). The majority of students in APMA 0350, 0360 have taken a linear algebra course. Linear Algebra may be taken concurrently with APMA 0350, 0360 but some material may not be covered before it is needed and the student will be expected to cover this material independently.

Prerequisites Summary: MATH 0090, 0100, 0180/0350, and 0520/0540

Introductory Courses:
1st year: Finish calculus sequence and linear algebra in the Math department
2nd year:

Differential Equations (Note recommended prerequisites above)

APMA 0330, 0340 OR APMA 0350, 0360
(intended for majors in the physical sciences/engineering)

Statistics
APMA 1650 (Prereq: MATH 0090, 0100)
Roadmap for Choosing Courses Continued

Diff Eqs (0330, 0340 or 0350, 0360)

Linear Algebra (MATH 0520/0540)

Statistics (1650)

3rd and 4th years:

PDEs

Bio Systems

Numerical Analysis

Operations Research

Dynamical Systems

Statistics*

1330

1070

1170

1200

1210

1360 (senior seminar)

1660, 1680, 1690, 1700

1080

1180

1670

4th year:

Senior Seminars:

Courses numbered 1930 or 1940 fulfill the senior seminar requirement and the topics vary from year to year. Note: there are other courses such as 1360 which may also fulfill the senior seminar requirement.

Independent Study:

Courses numbered 1950, 1960, or 1970 are reserved for independent studies and should be scheduled with the supervising faculty member.
Sample Course Programs

Regardless of which upper-level courses are chosen to fulfill concentration requirements, all students concentrating in Applied Mathematics take the following core courses:

**Core Courses**

- Calculus sequence: Math 0090, 0100, 0180 (or 0350).
  Some students may have advanced placement of transfer credit for these courses. Please speak with the Mathematics department about placement or credit for calculus courses.
- Linear Algebra: MATH 0520 or preferably 0540
- Differential Equations: APMA 0350 and 0360
- Computing Course: APMA 0090 or 0160 or CSCI 0040, 0150, or 0170

After the core courses there are many options for students. The following are just a few possible outlines of courses to fulfill the ScB degree requirements in Applied Mathematics. Since many courses are sequential or have prerequisites it is important to outline your course of study to ensure that you will have time to complete the requirements.

The following examples fulfill the 6 required unspecified 1000-level courses and the required core courses; they do not include the extra unspecified courses needed to complete the concentration.

*For those interested in Probability, Statistics, or Finance:*

<table>
<thead>
<tr>
<th>Semester I</th>
<th>Semester II</th>
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<tbody>
<tr>
<td>Math 0180/0350 (Calculus)</td>
<td>Math 0520/0540 (Linear Algebra)</td>
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<td></td>
<td>Computing course</td>
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<table>
<thead>
<tr>
<th>Semester III</th>
<th>Semester IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>APMA 0350 (Diff Eq)</td>
<td>APMA 0360 (Diff Eq)</td>
</tr>
<tr>
<td>APMA 1650 (Stats)</td>
<td>APMA 1660 (Stats)</td>
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<td></td>
<td>Computing course (if not taken already)</td>
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<table>
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<tr>
<th>Semester V/VII</th>
<th>Semester VI/VIII</th>
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<tbody>
<tr>
<td>APMA 1690 (Computational Prob. And Stat)</td>
<td>APMA 1720 (Monte Carlo Methods/Finance)</td>
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For those interested in considering Graduate School:

<table>
<thead>
<tr>
<th>Semester I</th>
<th>Semester II</th>
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<tbody>
<tr>
<td>Math 0180/0350 (Calculus)</td>
<td>Math 0520/0540 (Linear Algebra)</td>
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<tr>
<td>Computing course</td>
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<table>
<thead>
<tr>
<th>Semester III</th>
<th>Semester IV</th>
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<tbody>
<tr>
<td>APMA 0350 (Diff Eq)</td>
<td>APMA 0360 (Diff Eq)</td>
</tr>
<tr>
<td>APMA 1650 (Stats)</td>
<td>APMA 1660 (Stats)</td>
</tr>
<tr>
<td>Computing course (if not taken already)</td>
<td>MATH 1010 (Analysis)</td>
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<table>
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<tr>
<th>Semester V/VII</th>
<th>Semester VI/VIII</th>
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<tbody>
<tr>
<td>APMA 1170 (Numerical Analysis)</td>
<td>APMA 1180 (Numerical Analysis)</td>
</tr>
<tr>
<td>APMA 1210 (Operations Research)</td>
<td>APMA 1360 (Dynamics)</td>
</tr>
<tr>
<td>APMA 1930 (Senior Seminar)</td>
<td>APMA 1940 (Senior Seminar)</td>
</tr>
<tr>
<td>APMA 1970 (Independent Study/Thesis)</td>
<td>Graduate level courses</td>
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Other suggestions are MATH 1260 (Complex Analysis) or MATH 1530 (Algebra), which are accepted for the Applied Mathematics concentration.

For those interested in a computational approach:

<table>
<thead>
<tr>
<th>Semester I</th>
<th>Semester II</th>
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<tbody>
<tr>
<td>Math 0180/0350 (Calculus)</td>
<td>Math 0520/0540 (Linear Algebra)</td>
</tr>
<tr>
<td>Computing course</td>
<td>Computing course</td>
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</table>

<table>
<thead>
<tr>
<th>Semester III</th>
<th>Semester IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>APMA 0350 (Diff Eq)</td>
<td>APMA 0360 (Differential Equations)</td>
</tr>
<tr>
<td>APMA 1170 (Numerical Analysis)</td>
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For those interested in insurance mathematics:

Although not specifically designed for this purpose, some of the Division's courses offer preparation for several of the Associateship examinations for the Society of Actuaries and the Casualty Actuarial Society. In particular, APMA 1650 closely matches the material for Exam 1/P, and most students will be able to take Exam 1/P after APMA 1650 with a small amount of additional studying. Also, APMA 1700 is a good preparation for Exam 3L/MLC. Much of the stochastic modeling and simulation material for Exams 3/MFE and Exam 4/C is covered in APMA 1720 and APMA 1200.

Independent Study

If you are interested in learning about a specific topic or area that we do not offer courses on, you could consider taking APMA 1970 (Independent Study). To enroll in an Independent Study, students need to find a faculty sponsor who is willing to work with them on a syllabus, agree on a form of assessment, and advise them over the course of the semester. The Division’s concentration advisors can help you identify potential faculty sponsors if you need help or advice.

Senior Seminars

The Division usually offers at least two senior seminars each year. The topics vary from year to year, so please check on Banner for current listings. Independent study and some of our advanced courses such as APMA 1360 can be used instead of the senior seminar to satisfy the senior seminar requirement. Please note that seminar subjects change all the time, so if you see something that appears interesting in your junior year, you should explore the class and see if it is right for you.
The Writing Requirement

As part of Brown’s writing requirement, all students must demonstrate that they have worked on their writing both in their general studies and their concentration. Students in their first two years will generally take courses in English, Comparative Literature, or those marked "WRIT" in Banner; those who have not taken such classes should upload a writing sample into ASK before they declare a concentration. In their final two years, students are encouraged to explore writing in the concentration.

There are a number of ways in which Applied Mathematics concentrators can work on their writing as part of their concentration, and we now list a few examples:

- Enrolling in a senior seminars (APMA 1930 or 1940);
- Enrolling in an independent studies (APMA 1970);
- Writing an honors thesis;
- A “WRIT” course taken during your final two years;
- Uploading an essay of 5-10 pages length on a topic in applied math to ASK: this could be a project report written as part of an applied math class (such as APMA 1360) or a reflection about the courses you have taken in your concentration.

New concentrators need to outline in their concentration declaration how they intend to work on their writing during their junior and senior years. If you have questions about the writing requirement, please contact one of the applied mathematics concentration advisors.
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 should be studied in some depth.

Applied Mathematics Program — A.B. degree

Prerequisite: MATH 0090, 0100 or their equivalent.
Program: Ten additional semester courses approved by the Division of Applied Mathematics. These classes must include:

- MATH 0180 and 0520.
- APMA 0350 and 0360.
- One course on programming from the following list: APMA 0090, 0160, 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 1000-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 — Sc.B. degree

Eighteen approved semester courses in mathematics, applied mathematics, engineering, the natural or social sciences. These classes must include:

- MATH 0090, 0100, 0180, and 0520.
- APMA 0350 and 0360.
- A senior seminar: APMA 1930 or 1940 or an approved equivalent.
- One course on programming from the following list: APMA 0090, 0160, 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 1000-level or higher level courses taught by the Division of Applied Mathematics. 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 Mathematics–Biology — Sc.B. degree**

The Applied Math – Biology concentration recognizes that mathematics is essential to address many modern biological problems in the post genomic era. Specifically, high throughput technologies have rendered vast new biological data sets that require novel analytical skills for the most basic analyses. These technologies are 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. Nevertheless, the application of these methods in areas of biology from molecular genetics to evolutionary biology has grown very rapidly in with the availability of vast amounts of genomic sequence data.

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 academia.

**Requirements:**

- APMA 0350 (or 0330)
- APMA 0360 (or 0340)
- APMA 1650
- One other approved 1000 level APMA course.
- Four biology courses agreed upon by the student and advisor (see below for some possible areas of emphasis).
- MATH 0090, 0100 (or 0170), 0180 and 0520 (or an applied algebra course).
- CHEM 0330; (organic chemistry and biochemistry are also recommended for concentrations emphasizing these areas).
- PHYS 0030, 0040 or PHYS 0050, 0060
- Two additional courses in applied math, biology, chemistry, math, or physics. At least one of these must be a directed research course that reflects the theme of this program (e.g., APMA 1970; BIOL 1950/1960).

**Possible areas of emphasis and suggested courses include:**
• Biochemistry: BIOL 0280; 1270; and CHEM 0350, 0360; 1230, 1240.
• Cells, tissues, and organs: BIOL 0800; 1100; 1190; and/or appropriate bioengineering courses, such as: BIOL 1090; 1120; 1140.
• Neurosciences: NEUR courses; APMA 0410.
• Population biology and ecology: BIOL 0380; 0420; 0430; 0450; 0480; 1410; 1420; 1430; 1460.
• Genetics: BIOL 0470; 1410.

Concentration Advisors:

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

Professor Charles Lawrence, 3-1479, Room 204, 182 George Street

Applied Mathematics–Computer Science — Sc.B. degree

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. It prepares 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.

Sc.B. degree in Applied Mathematics–Computer Science — Normal Track

Prerequisites (2 courses):

Mathematics
• An approved math course (any MATH course beyond 0090 except for 0420, or APMA 0330).

Concentration Requirements (16 or 17 courses):

Core – Math
• MATH 0180 or 0350
• MATH 0520 or 0540, or CSCI 0530

Core – Applied Mathematics
• APMA 0350
• APMA 0360
• APMA 1170 or 1180

Core – Computer Science
• (CSCI 0150 and CSCI 0160) or (CSCI 0170 and CSCI 0180) or (CSCI 0190 and an additional CS course not otherwise used: this can be CSCI 0180 or another intermediate-level or advanced course)

• Three of the following CSCI courses (of which one must be math-oriented and one systems-oriented) from
  o CSCI 0220 (math)
  o CSCI 0450 (math)
  o CSCI 0320 (systems)
  o CSCI 0330 (systems)
  o CSCI 0510 (math)

Additional Requirements

• Three 1000 level Computer Science courses. These three courses must include a pair of courses with a coherent theme. A list of approved pairs may be found at the approved pairs web page: [http://www.cs.brown.edu/ugrad/concentrations/approvedpairs.html](http://www.cs.brown.edu/ugrad/concentrations/approvedpairs.html). You are not restricted to the pairs on this list, but any pair not on the list must be approved by the director of undergraduate studies.

• Three 1000 level Applied Mathematics courses approved by the concentration advisor, of which two should constitute a standard sequence or address a common theme. Typical sequences include: APMA 1200/1210 and APMA 1650/1660.

• A capstone course: a one semester course, normally taken in the student’s last undergraduate year, in which the student (or group of students) use a significant portion of their undergraduate education, broadly interpreted, in studying some current topic in depth, to produce a culminating artifact such as a paper or software project.

_Sc.B. degree in Applied Mathematics–Computer Science — Professional Track_

The professional track has the same concentration requirements as the normal track described above with the added requirement of two summer Computer-Science-related internships or research experiences. Students are required to write a reflective essay after each summer experience that addresses how the summer work related to their coursework, what they learned that they could not or did not learn during regular coursework, and that more generally reflects on their experience and the outcomes of their internship or research experience. Students need to upload these essays to ASK and receive approval from their advisor for each essay.
**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.

**A.B. degree in Applied Mathematics–Economics — Advanced Economics Track**

**Prerequisites:** MATH 0100, 0520.

**Applied Mathematics Requirements:**

(a) APMA 0350 and 0360 (APMA 0330 and 0340 may be substituted with advisor approval). 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, 1740, 1750, MATH 1010. No course may be used to simultaneously satisfy (a) and (b).

**Economics Requirements:**

ECON 1130 (or 1110 with permission), 1210, 1630; plus at least three other 1000-level economics courses. Of those three courses, at least two must be chosen from the “mathematical-economics” group. This group comprises ECON 1170, 1465, 1470, 1640, 1750, 1759, 1810, 1850, 1860, and 1870.

**Sc.B. degree in Applied Mathematics–Economics —Advanced Economics Track**

**Prerequisites:** MATH 0100, 0520.

**Applied Mathematics Requirements:**
(a) APMA 0350 and 0360 (APMA 0330 and 0340 may be substituted with advisor approval). One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. One course from APMA 1200, 1210. APMA 1650.

(b) Two courses from APMA 1200, 1210, 1660, 1670, 1680, 1690, 1700, 1740, MATH 1010. No course may be used to simultaneously satisfy (a) and (b).

**Economics Requirements:**

ECON 1130 (or 1110 with permission), 1210 and 1630; plus at least five other 1000-level economics courses. Of the five courses, three must be chosen from the “mathematical-economics” group. This group comprises ECON 1170, 1465, 1470, 1640, 1750, 1759, 1810, 1850, 1860, and 1870.

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**A.B. degree in Applied Mathematics–Economics — Mathematical Finance Track**

**Prerequisites:** MATH 0100, 0520.

**Applied Mathematics Requirements:**

(a) APMA 0350 and 0360 (APMA 0330 and 0340 may be substituted with advisor approval). 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, 1740, MATH 1010. (APMA 1720 is most preferred in this list.)

**Economics Requirements:**

ECON 1130 (or 1110 with permission), 1210, 1630; plus three other 1000-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, 1760, 1765, 1770 and 1790. The "mathematical economics" group comprises ECON 1170, 1465, 1470, 1640, 1750, 1759, 1810, 1850, 1860, and 1870. No course may be used to simultaneously satisfy the "financial economics" and the "mathematical economics" requirements.

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**Sc.B. degree in Applied Mathematics–Economics — Mathematical Finance Track**
Prerequisites: MATH 0100, 0520.

Applied Mathematics Requirements:

(a) APMA 0350 and 0360 (APMA 0330 and 0340 may be substituted with advisor approval). One course from APMA 0160, CSCI 0040, CSCI 0150, CSCI 0170. APMA 1200. APMA 1650.

(b) Two courses from APMA 1180, 1330, 1660, 1670, 1680, 1690, 1700, 1720, 1740. MATH 1010. (APMA 1720 is most preferred in this list).

Economics Requirements:

ECON 1130 (or 1110 with permission), 1210 and 1630; plus five other 1000-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, 1760, 1765, 1770 and 1790. The "mathematical economics" group comprises ECON 1170, 1465, 1470, 1640, 1750, 1759, 1810, 1850, 1860, and 1870. No course may be used to simultaneously satisfy the "financial economics" and the "mathematical economics" requirements.
Concentration Advisors

Please see one of our concentration advisors for further information and assistance.

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Undergraduate Research

Many faculty members in the Division offer opportunities for undergraduates who want to pursue research projects in the summer or, sometimes, during the academic year. Interested undergraduates should get in touch with a faculty member; your concentration advisor can help you identifying faculty sponsors. If you plan to apply for an Undergraduate Teaching and Research Award (UTRA) to fund your summer research, it is important to talk with prospective faculty advisors early on, and ideally before the winter break.

Another option is to apply for one of the many REU (Research Experience for Undergraduates) Summer Programs that are offered at universities and colleges throughout the US. The American Mathematical Society keeps an up-to-date list of such activities.

Application deadlines are usually in February or March. Financial support typically requires that applicants are US citizens, nationals, or permanent residents.

Honors in Applied Mathematics

Students concentrating in applied mathematics whose work has consistently demonstrated superior quality and culminated in a senior thesis of distinction will be recommended by the division of applied mathematics for Honors from the University (magna cum laude) at graduation.

Students seeking honors must complete at least two semesters of project work with a faculty member in applied mathematics, or a closely related field. Students must register for credit for the project via APMA 1970 or a similar independent study course. The project work culminates in a written thesis, which is reviewed by the thesis advisor and a second reader, also conversant with the field of inquiry. When the primary advisor for the thesis is not in applied mathematics, the thesis must also be evaluated by a second reader who is on the faculty of applied mathematics. The thesis work must be presented in the form of an oral presentation at the end of the senior year at the Undergraduate Research Day in applied mathematics.

Excellence in grades within the concentration as well as a satisfactory evaluation by the advisors are required for Honors. The student's grades must place them within the upper 20% of their cohort, in accordance with university policy.

Students who wish to apply for honors are advised to find a thesis advisor by the end of their junior year. Students must register for an independent study with their advisor for no less than two semesters and formally declare their intention to their academic advisor to apply for honors by Oct. 31 of their senior year.
Honors in Joint Concentrations

Please note that the deadlines for declaring honor differ between different joint concentrations because of the differing needs and scale of each program.

Applied Mathematics-Biology

Honors in the applied math-biology concentration is based primarily upon an in-depth, original research project carried out under the guidance of a Brown (and usually Applied Math or BioMed) affiliated Faculty Advisor. Projects must be conducted for no less than two full semesters, and students must register for credit for the project via APMA 1970 or BIOL 1950/1960 or similar independent study courses. The project culminates the writing of a thesis, which is reviewed by the thesis advisor and a second reader. It is essential that the student have one advisor from the biological sciences and one in applied mathematics. The thesis work must be presented in the form of an oral presentation or poster at the annual Undergraduate Research Day in either applied mathematics or biology. For information on registering for BIOL 1950/1960, please see biology.brown.edu/bug/

Excellence in grades within the concentration as well as a satisfactory evaluation by the advisors are also required for Honors. The student's grades must place them within the upper 20% of their cohort, in accordance with the university policy on honors.

Students in the AM-Bio concentration interested in honors should apply via the division of applied mathematics. Students must email the chair of the undergraduate committee in applied mathematics of their intention to declare honors by the following dates: January 30 of their last semester for a May graduation, and Labor Day in their last semester for a December graduation. They must also abide by all deadlines for undergraduate thesis preparation in the biological sciences as listed at: http://biology.brown.edu/bug/guidelines-and-requirements-for-honors.html

Applied Mathematics-Computer Science

Students in the joint concentration must have a primary advisor who is on the faculty of either applied mathematics or computer science. Students must abide by the honors requirements of the advisor’s department.

Applied Mathematics-Economics

Honors in the applied math-economics concentration is based primarily upon an in-depth, original research project carried out under the guidance of a Faculty Advisor in applied mathematics or economics. Projects must be conducted for no less than two full semesters, and students must register for credit for the project via APMA 1970 or ECON 1960/1970 or a similar
approved independent study courses. The project culminates in the writing of a thesis, which is reviewed by the thesis advisor and a second reader. It is essential that the student have one advisor from economics and one in applied mathematics.

Students are advised to first consult with an advisor on the suitability of their proposed work for the joint concentration by the end of their junior year, or early in their senior year. Students must formally declare their intention to apply for honors in the concentration to their advisor no later than the last day to add or drop a class in the fall semester of their senior year.

**Prizes**

**The Rohn Truell Premium Prize**

Every year, 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 2015-2016

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Courses in Applied Mathematics

Introductory Courses

APMA 0120. 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 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 0200. Introduction to Modeling
This course provides an introduction to the mathematical modeling of selected biological, chemical, engineering, and physical processes. The goal is to illustrate the typical way in which applied mathematicians approach practical applications, from understanding the underlying problem, creating a model, analyzing the model using mathematical techniques, and interpreting the findings in terms of the original problem. Single-variable calculus is the only requirement; all other techniques from differential equations, linear algebra, and numerical methods, to probability and statistics will be introduced in class. Prerequisites: MATH 0100 or equivalent.

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 0640. Data Analysis Big and Small
A first course in statistics emphasizing a principled approach to data analysis through the use of probabilistic simulations: The focus is on the fundamental concepts of statistical inference and probability, and their application in modern data analysis. The premise of this course is that stochastic simulations provide an alternative to calculus for learning the fundamental concepts of statistical inference and probability theory that are typically covered in more advanced courses. From this foundation we will explore how big data impact both the questions and answers in data science. Suitable alternative to APMA0650. No prerequisites are required.

APMA 0650. Essential Statistics

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

APMA 0340/0360. Methods of Applied Mathematics II
Prerequisites: MATH 0090, 0100. It is 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 currently 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**


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**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.

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 1080/2080. 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**


**APMA 1850 - Introduction to High Performance Parallel Computing**

No description available.

**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.

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. Operations Research: 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 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 1650/1660 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 0100 - Elementary Probability for Applications**

This course serves as an introduction to probability and stochastic processes with applications
to practical problems. It will cover basic probability and stochastic processes such as basic concepts of probability and conditional probability, simple random walk, Markov chains, continuous distributions, Brownian motion and option pricing. Enrollment limited to 20 first year students.

**APMA 1650/1655. Statistical Inference I**
APMA 1650 is an integrated first course in mathematical statistics. The first half of APMA 1650 covers probability and the last half is statistics, integrated with its probabilistic foundation. Specific topics include probability spaces, discrete and continuous random variables methods for parameter estimation, confidence intervals and hypothesis testing. Students may opt to enroll in 1655 for more in depth coverage of the above topics. Enrollment in 1655 will include an optional recitation section and required additional individual work. Applied Math concentrators are encouraged to take 1655. Prerequisite (for either version): MATH 0100, 0170, 0180, 0190, 0200, or 0350.

**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 1700. The Mathematics of Insurance**
The course consists of two parts: the first treats life contingencies, i.e. the construction of models for individual life insurance contracts. The second treats the Collective Theory of Risk, which constructs mathematical models for the insurance company and its portfolio of policies as a whole. Suitable also for students proceeding to the Institute of Actuaries examinations. Prerequisites: Probability Theory to the level of APMA 1650 or MATH 1610.

**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.

**APMA 1720. Monte Carlo Simulation with Applications to Finance**
The course will cover the basics of Monte Carlo and its applications to financial engineering: generating random variables and simulating stochastic processes; analysis of simulated data; variance reduction techniques; binomial trees and option pricing; Black-Scholes formula; portfolio optimization; interest rate models. The course will use MATLAB as the standard simulation tool. Prerequisites: APMA 1650 or MATH 1610.

**APMA 1740/2610. Recent Applications of Probability and Statistics**
This course develops the mathematical foundations of modern applications of statistics to the computational, cognitive, engineering, and neural sciences. The course is rigorous, but the emphasis is on application. Topics include: Gibbs ensembles and their relation to maximum entropy, large deviations, exponential models, and information theory; statistical estimation and the generative, discriminative and algorithmic approaches to classification; graphical models, dynamic programming, MCMC computing, parameter estimation, and the EM algorithm. For 2,000-level credit enroll in 2610; for 1,000-level credit enroll in 1740. Rigorous calculus-based statistics, programming experience, and strong mathematical background are essential. For 2610, some graduate level analysis is strongly suggested.

**APMA 1860. Graphics and Networks**
Selected topics about the mathematics of graphs and networks with an emphasis on random graph models and the dynamics of processes operating on these graphs. Topics may include: empirical properties of biological, social, and technological networks (small-world effects, scale-free properties, transitivity, community structure); mathematical and statistical models of random graphs and their properties (Bernoulli random graphs, preferential attachment models, stochastic block models, phase transitions); dynamical processes on graphs and networks (percolation, cascades, epidemics, queuing, synchronization). Prerequisites: APMA 0360, MATH
0520, APMA 1650 or MATH 1610, or equivalents of these, and programming experience. APMA 1200 or equivalent strongly recommended.

**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 1930J. Mathematics of Random Networks**
An introduction to the emerging field of random networks and a glimpse of some of the latest developments. Random networks arise in a variety of applications including statistics, communications, physics, biology and social networks. They are studied using methods from a variety of disciplines ranging from probability, graph theory and statistical physics to nonlinear dynamical systems. Describes elements of these theories and shows how they can be used to gain practical insight into various aspects of these networks including their structure, design, distributed control and self-organizing properties. Prerequisites: Advanced calculus, basic knowledge of probability.

**APMA 1930N. Stochastic Models of Neuronal Networks**
Senior seminar on stochastic models of neuronal network dynamics. Topics will include: dynamics of sparsely connected networks; various regimes and phase transitions; role of network structure and network motifs; spike-timing-dependent plasticity. Some of the tools: mean-field approach; eigenvalue spectra of random matrices; numerical simulation. Required background: calculus, basic probability. Background in neuroscience is helpful but not required. We will start with a few lectures to set up the stage.
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**
Multigrid 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 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 macromolecules, 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 1940Q. Filtering Theory
Filtering (estimation of a “state process” from noisy data) is an important area of modern
statistics. It is of central importance in navigation, signal and image processing, control theory
and other areas of engineering and science. Filtering is one of the exemplary areas where the
application of modern mathematics and statistics leads to substantial advances in engineering.
The goal of the course is to provide a student with the working knowledge sufficient for cutting
dge research in the field of nonlinear filtering and its practical applications. The topics we will
concentrate on include: hidden Markov models, Kalman and Wiener filters, optimal nonlinear
filtering, elements of Ito calculus and Wiener chaos, Zakai and Kushner equations, spectral
separating filters and wavelet based filters, numerical implementation of filters. We will
consider numerous applications of filtering to speech recognition, analysis of financial data,
target tracking and image processing. The course will be made accessible to undergraduate
students. No prior knowledge in the field is required but a good understanding of basic
Probability Theory (APMA 1200 or APMA 2630) is important.
1940R. Linear and Nonlinear Waves
From sound and light waves to water waves and traffic jams, wave phenomena are everywhere around us. In this seminar, we will discuss linear and nonlinear waves as well as the propagation of wave packets. Among the tools we shall use and learn about are numerical simulations in Matlab and analytical techniques from ordinary and partial differential equations. We will also explore applications in nonlinear optics and to traffic flow problems. Prerequisites: MATH 0180 and either APMA 0330-0340 or APMA 0350-0360. No background in partial differential equations is required.

1940S. Topics in Applied Differential Equations
The course will cover several topics of ordinary differential equations arising from other disciplines such as physics, chemistry, biology, and engineering, with an emphasis on the modeling of various underlining equations. The course will also be supplemented with a use of computer algebra systems like MATHEMATICA.

1940U. Filtering of Prediction of Hidden Markov Models
This course is built around the problem of estimating noisily observed dynamics from a sequence of data. This is a fascinating engineering problem with strong ties to probability theory and with numerous scientific and technological applications. Topics covered will include conditioning and optimal estimates, filtering and interpolation of Markov chains, elements of stochastic calculus and Wiener processes, and the continuous-time Kalman filter. Applications of hidden Markov models to problems arising in finance, genetics, and epidemiological modeling will also be considered.

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, 0160. 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 0160  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 0310  Mechanics of Solids and Structures
- ENGN 0520  Electrical Circuits and Signals
- ENGN 0720  Thermodynamics
- ENGN 0810  Fluid Mechanics
- ENGN 1210  Biomechanics
- ENGN 1220  Neuroengineering Control of Movement
- ENGN 1570  Linear Systems Analysis
- ENGN 1580  Communication Systems
- ENGN 1630  Digital Electronics Systems Design
- ENGN 1660  Automatic Control Systems
- ENGN 1750  Advanced Mechanics of Solids
- ENGN 1860  Advanced Fluid Mechanics
Department of Cognitive, Linguistic & Psychological Sciences

CLPS 0030  Introduction to Linguistic Theory
CLPS 1491  Neural Modeling Laboratory

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  Weather and Climate
GEOL 1600  Environmental and Engineering Geophysics
GEOL 1610  Solid Earth Geophysics
GEOL 1620  Continuum Physics of the Solid Earth
GEOL 1960  Special Topics in Geological Sciences

Computer Science

There is a standard concentration in Applied Mathematics - Computer Sciences for the Sc.B. degree which lists 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 Brown’s School of Public 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

Economics

ECON 0110 - Principles of Economics
ECON 0180 - First Year Seminar
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 1185 - The Welfare State
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 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 1765 - Finance, Regulation, and the Economy: Research
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