Undergraduate Handbook

A Guide to Undergraduate Programs

Division of Applied Mathematics, Brown University

March 2020

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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:

American Mathematical Society (AMS)	http://www.ams.org/profession/career-info/career-index
Society for Industrial and Applied Mathematics (SIAM)	http://www.siam.org/careers/
Mathematical Association of America (MAA)	http://www.maa.org/careers/
American Statistical Society (ASA)	http://www.amstat.org/
Association for Women in Mathematics (AWM)	http://www.awm-math.org/
Institute for Operations Research and the Management Sciences (INFORMS)	http://www.informs.org
National Academy of Sciences	http://www.nap.edu
Casualty Actuarial Society	http://www.casact.org
Society of Actuaries	http://www.soa.org

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.

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 or 1655 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)
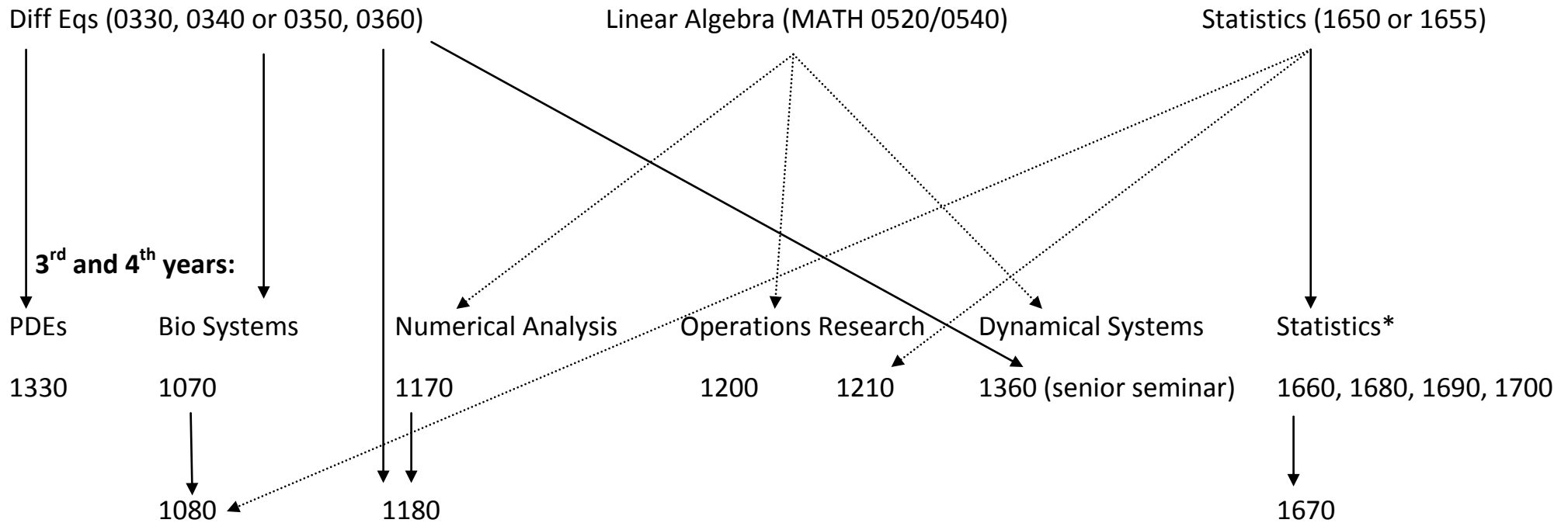
APMA 0330, 0340   OR   APMA 0350, 0360
(intended for majors in the physical sciences/engineering)   (intended for Applied Mathematics majors)

Statistics
APMA 1650 or 1655 (Prereq: MATH 0090, 0100)

Roadmap for Choosing Courses Continued

Diff Eqs (0330, 0340 or 0350, 0360)   Linear Algebra (MATH 0520/0540)   Statistics (1650 or 1655)

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

* APMA 1650 is a prerequisite to all other statistics courses

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:

The course number 1970 (and their section numbers) is 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:

Semester I	Semester II
Math 0180/0350 (Calculus)	Math 0520/0540 (Linear Algebra)
	Computing course

Semester III	Semester IV
APMA 0350 (Diff Eq)	APMA 0360 (Diff Eq)
APMA 1650 or 1655 (Stats)	APMA 1660 (Stats)
	Computing course (if not taken already)

Semester V/VII	Semester VI/VIII
APMA 1690 (Computational Prob. And Stat)	APMA 1720 (Monte Carlo Methods/Finance)

APMA 1710 (Information Theory)   APMA 1200 (Operations Research)

APMA 1930 (Senior Seminar)   or   APMA 1940 (Senior Seminar)

For those interested in considering Graduate School:

Semester I   **Semester II**

Math 0180/0350 (Calculus)   Math 0520/0540 (Linear Algebra)

                                          Computing course

Semester III   **Semester IV**

APMA 0350 (Differential Equations)   APMA 0360 (Diff Eq)

APMA 1650 or 1655 (Statistics)   APMA 1660 (Stats)

                                          Computing course (if not taken already)

                                          MATH 1010 (Analysis)

Semester V/VII   **Semester VI/VIII**

APMA 1170 (Numerical Analysis)   APMA 1180 (Numerical Analysis)

APMA 1210 (Operations Research)   APMA 1360 (Dynamics)

APMA 1930 (Senior Seminar)   or   APMA 1940 (Senior Seminar)

APMA 1970 (Independent Study/Thesis)   Graduate level courses

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:

Semester I   **Semester II**

Math 0180/0350 (Calculus)   Math 0520/0540 (Linear Algebra)

Computing course   Computing course

Semester III   **Semester IV**

APMA 0350 (Differential Equations)   APMA 0360 (Differential Equations)

APMA 1170 (Numerical Analysis)

APMA 1650 or 1655 (Stats)

Semester V/VII		Semester VI/VIII
APMA 1210 (Operations Research)		APMA 1180 (Numerical Analysis)
APMA 1710 (Information Theory)		
APMA 1690 (Computational Prob. And Stat.)		
APMA 1930 (Senior Seminar)	or	APMA 1940 (Senior Seminar)

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 or 1655 closely matches the material for Exam 1/P, and most students will be able to take Exam 1/P after APMA 1650 or 1655 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 about which 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 which are 1930 and 1940 (with section numbers). 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. In semesters 5 - 7, students are encouraged to work on their writing in the concentration. The second writing requirement must be fulfilled by the end of the penultimate (usually the seventh) semester. 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 and completing a senior seminar in the 7th semester (APMA 1930 or 1940);
- Enrolling in and completing a "WRIT" course from any department in semesters 5 - 7;
- Students in the class of 2019 and earlier only**: 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 must outline in their concentration declaration how they intend to work on their writing in semesters 5 - 7. If you have questions about the writing requirement, please contact one of the applied mathematics concentration advisors.

Starting from fall 2016 and ending with the class of 2019, whether or not a student is an honor's candidate, they will still need to complete the writing requirement with either a sample of writing uploaded to ASK or a WRIT course by the end of the 7th semester.

Rubric for writing samples to fulfill the second writing requirement, ending with students in the class of 2019:

Purpose	The writing has a clear purpose or argument that is readily apparent to the reader.
Content	Balanced presentation of relevant and legitimate information that clearly supports a central purpose or argument and shows a thoughtful, in-depth analysis of a significant topic. Reader gains important insights.
Organization	The ideas are arranged logically to support the purpose or argument which are clearly linked to each other. The reader can follow the line of reasoning.
Sentence Structure	Tone is appropriate for an undergraduate research paper. Sentences are well-phrased and varied in length and structure. They flow smoothly from one to another. Word choice is consistently precise and accurate.
Grammar and Spelling	The writing is free, or almost free, of errors
Length	5-10 pages.

References	Compelling evidence from professionally legitimate sources is given to support claims. Attribution is clear and fairly represented. The reader is confident that the information and ideas can be trusted.

Concentration Requirements

For comprehensive information about the requirements for the various applied mathematics concentrations, please visit: https://bulletin.brown.edu/the-college/concentrations/

Concentration Advisors

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

Elie Bienenstock, All Concentrations Associate Professor of Applied Mathematics and Neuroscience Room 228, 182 George Street 401-863-3120 Elie_Bienenstock@Brown.edu	Constantine Dafermos, All Concentrations Alumni/Alumnae University Professor of Applied Mathematics Room 217, 182 George Street 401-863-1483 Constantine_Dafermos@Brown.edu
Paul Dupuis, Director All Concentrations Room 117, 182 George Street 401-863-3238 Paul_Dupuis@Brown.edu	Charles Lawrence, APMA-Bio Professor of Applied Mathematics Room 204, 182 George Street 401-863-1479 Charles_Lawrence@Brown.edu
John Mallet-Paret, All Concentrations George I. Chase Professor of the Physical Sciences Room 205, 182 George Street 401-863-2209 John_Mallet-Paret@Brown.edu	Martin Maxey, All Concentrations Professor of Applied Mathematics and Engineering Room 316, 170 Hope Street 401-863-1482 Martin_Maxey@Brown.edu
Bjorn Sandstede, All Concentrations Royce Family Professor of Teaching Excellence and Professor of Applied Mathematics Room 212, 170 Hope Street 401-863-2815 Bjorn_Sandstede@Brown.edu	Hui Wang, All Concentrations Associate Professor of Applied Mathematics Room 223, 182 George Street 401-863-2360 Hui_Wang@Brown.edu

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 the end of the 3ʳᵈ week of the 7ᵗʰ semester.

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. Please visit: https://bulletin.brown.edu/the-college/concentrations/apmc/

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. Please visit: https://bulletin.brown.edu/the-college/concentrations/apme/

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 2020-2021

COURSE NUMBER	SEMESTER	COURSE TITLE
APMA 0200	I	Introduction to Modellng
APMA 0330	I	Methods of Applied Mathematics I & II
APMA 0340	I	Methods of Applied Mathematics I & II
APMA 0350	I	Applied ODE's
APMA 0360	I	Applield PDE's
APMA 1080/2080	I	Inference Genomics/Molecular Biology
APMA 1170	I	Introduction to Computational Linear Algebra
APMA 1210	I	Operations Research Deterministic Models
APMA 1330	I	Applied PDE's II
APMA 1650	I	Statistical Inference I
APMA 1655	I	Statistical Inference I
APMA 1690	I	Computational Probability and Statistics
APMA 1930U	I	Introduction to Stochastic Differential Equations
APMA 1080/2080	I	Inference Genomics/Molecular Biology
DATA 1010	I	Introduction to Probability and Statistics Machine Learning
Course Number	**Semester**	**Course Title**
APMA 0160	II	Introduction to Scientific Computing
APMA 0330	II	Methods of Applied Mathematics I & II
APMA 0340	II	Methods of Applied Mathematics I & II
APMA 0350	II	Applied ODE's
APMA 0360	II	Applied PDE's
APMA 0650	II	Essential Statistics
APMA 1070	II	Quantitative Models of Biological Systems
APMA 1160	II	An Introduction to Numerical Optimization
APMA 1200	II	Operational Analysis: Probabilistic Models
APMA 1360	II	Topics in Chaotic Dynamics
APMA 1660	II	Statistical Inference II
APMA 1710	II	Information Theory
APMA 1720	II	Monte Carlo Simulation with Applications
APM 1740	II	Recent Applications of Probability and Statistics
APMA 1941	II	Undergraduate Topics Course

COURSE NUMBER	SEMESTER	COURSE TITLE
APMA 1940B	II	Undergraduate Topics Course

Courses in Applied Mathematics

Introductory Courses

APMA 0110. What's the Big Deal with Data Science?

This seminar serves as a practical introduction to the interdisciplinary field of data science. Over the course of the semester, students will be exposed to the diversity of questions that data science can address by reading current scholarly works from leading researchers. Through hands-on labs and experiences, students will gain facility with computational and visualization techniques for uncovering meaning from large numerical and text-based data sets. Ultimately, students will gain fluency with data science vocabulary and ideas. There are no prerequisites for this course.

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

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 provides a short introduction to probability and statistics.

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 II

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.

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 or 1655* 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 1160. An Introduction to Numerical Optimization

This course provides a thorough introduction to numerical methods and algorithms for solving non-linear continuous optimization problems. Aparticular attention will be given to the mathematical underpinnings to understand the theoretical properties of the optimization problems and the algorithms designed to solve them. Topics will include: line search methods, trust-region methods, nonlinear conjugate gradient methods, an introduction to constrained optimization (Karush-Kuhn-Tucker conditions, mini-maximization, saddle-points of Lagrangians). Some applications in signal and image processing will be explored. Prereq: functions of several variables (MATH 0180) or equivalent of this. Computational Linear Algebra (APMA 1170) or a similar course is recommended.

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.

APMA 1330. Applied Partial Differential Equations II
Mathematical methods based on functions of a complex variable. Fournier series and its applications to the solution of one-dimensional heat conduction equations and vibrating strings. Series solution and special functions. Vibrating membrane. Sturm-Liouville problem and eigenfunction expansions. Fournier transform and wave propagations.

APMA 1850. Introduction to High Performance Parallel Computing

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. Operations Research: 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 1655, 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 1330. Applied Partial Differential Equations II

Mathematical methods based on functions of a complex variable. Fournier series and its applications to the solution of one-dimensional heat conduction equations and vibrating strings. Series solution and special functions. Vibrating membrane. Sturm-Liouville problem and eigenfunction expansions. Fournier transform and wave propagations.

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 or 1655 provides an introduction to the general theory. Other courses, requiring AM 1650 or 1655 (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 1655, 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 1655, 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 1655, 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 1655, 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 1655, 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 1655, or MATH 1610, or equivalents of these, and programming experience. APMA 1200 or equivalent strongly recommended.

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. Starting in 2020, APMA 191 and 1911 are not allowed as a 1000-level elective. APMA 1910 is allowed for who took the course prior to Fall of 2019.

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 1655, 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.

APMA1930C. 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 1930I. Random Matrix Theory

In the past few years, random matrices have become extremely important in a variety of fields such as computer science, physics and statistics. They are also of basic importance in various areas of mathematics. This class will serve as an introduction to this area. The focus is on the basic matrix ensembles and their limiting distributions, but several applications will be considered. Prerequisites: MATH 0200 or 0350; and MATH 0520 or 0540; and APMA 0350, 0360, 1650, and 1660. APMA 1170 and MATH 1010 are recommended, but not required.

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 1930K. Stability of Differential Equations is Applications

Basic stability and instability analysis of differential equations will be covered. Various examples of physical and biological applications will be studied and shared with the class.

APMA 1930L. Fast Methods in Scientific Computing

Description to be announced

APMA 1930M. Applied Asymptotic Analysis

Many problems in applied mathematics and physics are nonlinear and are intractable to solve using elementary methods. In this course we will systematically develop techniques for obtaining quantitative information from nonlinear systems by exploiting small scale parameters. Topics will include: regular and singular perturbations, boundary layer theory, multiscale and averaging methods and asymptotic expansions of integrals. Along the way, we will discuss many applications including nonlinear waves, coupled oscillators, nonlinear optics, fluid dynamics and pattern formation.

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 1930O. Probabilities in Quantum and Statistical Mechanics

Just enough quantum and statistical mechanics (QM, SM) will be taught to enable a mathematically and physically informed discussion of some of the enduring mysteries surrounding these subjects. Examples: Schrodinger's equation and the abrupt transition from (weird) quantum worlds to familiar classical worlds; the general uncertainty principle; quantum teleportation; the impossibility of a local hidden variable theory for QM (Bell's Theorem) and

Einstein's objections; Conway's no-free-will theorem; quantum erasure; Boltzmann's local chaos, transport equation, and exchangeability; Poincare recurrence; the (possible) irrelevance of the ergodic theorem in SM (are measurements really akin to time averages?). Prerequisite: Strong mathematics background.

APMA 1930P. Mathematics and Climate

The study of Earth's climate involves many scientific components; mathematical tools play an important role in relating these through quantitative models, computational experiments and data analysis. The course aims to introduce students in applied mathematics to several of the conceptual models, the underlying physical principles and some of the ways data is analyzed and incorporated. Students will develop individual projects later in the semester. Prerequisites: APMA 0360, or APMA 0340, or written permission; APMA 1650/1655 is recommended.

APMA 1930Q. Mathematical Models of Cortical Dynamics

A Senior Applied Mathematics seminar on brain modeling, emphasizing: stochastic aspects of cortical dynamics; models of spike-timing-dependent plasticity; mean-field approaches to the analysis of large networks; the emergence of network motifs and their role in cortical function. Open to Neuroscience and CLPS students with adequate mathematical and computational preparation. Background in neuroscience desirable but not required. Prerequisites: APMA 1650/1655, 0330 and 0340.

APMA 1930R. Probabilities in Quantum Mechanics

We will start from scratch. The only prerequisites are some probability and a good facility with mathematics. We will be rigorous, while making a careful accounting of the (surprisingly few) conceptual assumptions that lead inexorably to consequences that are almost impossible to believe. With an eye on some of the most startling and vexing of these, we will construct a minimum mathematical foundation sufficient to explore: the abrupt transition from the weird quantum to the familiar classical world; the uncertainty principles; teleportation; Bell's theorem and the Einstein-Bohr debates; quantum erasure; the Conway-Kochen "free-will theorem"; and (unbreakable) quantum encryption.

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 1655, 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 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 edge 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.

APMA 1940T. Nonlinear Filtering for Hidden Markov Models

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 1940V. Topics in Coding Theory

This class covers two distinct areas: (1) algebraic coding theory; (2) examples of code breaking and design. Part (1) stresses cryptography, data compression, error correction and sphere packings. Part (2) will involve case studies of code breaking and code design in applications. Depending on student interest these may include decoding scripts (Ventris and Linear B), or design problems in synthetic biology (e.g. RNA folding and DNA self-assembly).

APMA 1940W. Randomized Algorithms for Counting, Integration and Optimization

We consider the construction and analysis of random methods for approximating sums and integrals, and related questions. Example, consider the problem of counting the number of vectors with integer components that satisfy a collection of linear equality and inequality

constraints. Depending on the number of constraints, this could be a problem of counting the number of needles in a haystack, and straightforward enumeration is impossible. There are now a variety of randomized methods that can attack this problem and other problems with similar difficult features. We survey some of the methods and the problems to which they apply.

APMA 1940X. Topics in Information theory and coding theory
This class builds on APMA 1710, but stresses applications of information and coding theory, rather than its mathematical foundations. The class provided an overview of widely used probabilistic methods and algorithms, such as Markov Chain Monte Carlo (MCMC), hidden Markov models (HMM), dynamic programming, belief propagation, and Bayesian inference. Information theory is used in combination with these algorithms as a framework to study applications such as code-breaking, speech recognition, image analysis and the study of genetic sequences. This class is best suited to students looking for topics for senior theses or capstone classes in applied mathematics, computer science and mathematics.

APMA 1940Y. Wavelets and Applications

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 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