

# Mathematics

The Mathematics Department at Brown balances a lively interest in students and teaching with a distinguished research reputation. Our several strong research groups, Analysis, Algebraic Geometry, Geometry and Topology, and Number Theory, all have active seminar schedules that draw local and international speakers. The undergraduate program in mathematics is designed to present students with challenging courses that will train them for any future they desire, be it in the economy, the government, or academe. We are also quite flexible in placing students; our goal being to discover a student's level of competence and then offering a stimulating course.

We support 40+ graduate students in a Ph.D. program whose graduates populate top mathematics departments and prominent positions in industry. Our joint graduate courses and seminars with the adjacent Division of Applied Mathematics add to the breadth of offerings available to our graduate students.

For additional information, please visit the department's website: <https://www.brown.edu/academics/math/>

## Mathematics Concentration Requirements

Mathematics is a grouping of sciences, including geometry, algebra, and calculus, that study quantity, structure, space, and change. Mathematics concentrators at Brown can explore these concepts through the department's broad course offerings and flexible concentration requirements. The concentration leads to either the Bachelor of Arts or Bachelor of Science degree (the latter is strongly recommended for students interested in pursuing graduate study in mathematics or related fields). Concentrators begin their learning with multivariable calculus, linear algebra, and abstract algebra. Beyond these prerequisites, students take a variety of advanced topics on the 1000 level based on their interests. After sufficient preparation and with permission of the instructor, students may also take courses on the 2000 level. Students also have the option of completing a thesis project.

Concentrators in mathematics should complete the prerequisites by the end of their sophomore year. It is strongly recommended that students take MATH 1010 before taking MATH 1630, (formerly MATH 1130).

### Prerequisites:

Multivariable calculus and linear algebra (choose one of the following sequences): 2

MATH 0180 & MATH 0520 Multivariable Calculus and Linear Algebra

MATH 0180 & MATH 0540 Multivariable Calculus and Linear Algebra With Theory

MATH 0200 & MATH 0520 Multivariable Calculus (Physics/Engineering) and Linear Algebra

MATH 0350 & MATH 0540 Multivariable Calculus With Theory and Linear Algebra With Theory

Or the equivalent

### Program:

MATH 1530 Abstract Algebra 1

Five other 1000- or 2000-level Mathematics courses. The year-long sequence 0750/0760 may be substituted for one of these course credits. 5

**Total Credits** 8

## Honors

Honors degrees may be recommended for students who have exhibited high achievement in mathematics. Candidates must complete at least eight mathematics courses at the 1000 or 2000 level with sufficiently good grades and must write an honors thesis under the guidance of a faculty member. The honors thesis is usually written while the candidate

is enrolled in MATH 1970. The candidate should consult with the concentration advisor for the precise grade requirements.

Concentrators in mathematics should complete the prerequisites by the end of their sophomore year. It is strongly recommended that students take MATH 1010 before taking MATH 1630, (formerly MATH 1130).

## Standard program for the Sc.B. degree

### Prerequisites:

Multivariate calculus and linear algebra (choose one of the following sequences): 2

MATH 0180 & MATH 0520 Multivariable Calculus and Linear Algebra

MATH 0180 & MATH 0540 Multivariable Calculus and Linear Algebra With Theory

MATH 0200 & MATH 0520 Multivariable Calculus (Physics/Engineering) and Linear Algebra

MATH 0350 & MATH 0540 Multivariable Calculus With Theory and Linear Algebra With Theory

Or the equivalent

### Program:

MATH 1630 Real Analysis I (formerly MATH 1130) 1

MATH 1640 Real Analysis II (formerly MATH 1140) 1

MATH 1530 Abstract Algebra 1

MATH 1540 Topics in Abstract Algebra 1  
or MATH 1560 Number Theory

Four other 1000- or 2000- level Mathematics courses. The year-long sequence 0750/0760 may be substituted for one of these course credits. 4

Four additional courses in mathematics, science, economics, or applied mathematics approved by the concentration advisor. 4

**Total Credits** 14

## Honors

Honors degrees may be recommended for students who have exhibited high achievement in mathematics. Candidates must complete at least eight mathematics courses at the 1000 or 2000 level with sufficiently good grades and must write an honors thesis under the guidance of a faculty member. The honors thesis is usually written while the candidate is enrolled in MATH 1970. The candidate should consult with the concentration advisor for the precise grade requirements.

Those interested in graduate study in mathematics are encouraged to take:

MATH 1630 Real Analysis I (formerly MATH 1130)

MATH 1640 Real Analysis II (formerly MATH 1140)

MATH 1460 Complex Analysis (formerly MATH 1260)

MATH 1710 Topology (formerly MATH 1410)

MATH 1540 Topics in Abstract Algebra

## Mathematics-Computer Science Concentration Requirements

Students may opt to pursue an interdisciplinary Bachelor of Science degree in Math-Computer Science, a concentration administered cooperatively between the mathematics and computer science departments. Course requirements include math- and systems-oriented computer science courses, as well as computational courses in applied math. Students must identify a series of electives that cohere around a common theme. As with other concentrations offered by the Computer Science department, students have the option to pursue the professional track of the ScB program in Mathematics-Computer Science.

## Requirements for the Standard Track of the Sc.B. degree.

### Prerequisites

Three semesters of Calculus to the level of MATH 0180, MATH 0200, or MATH 0350 3

MATH 0520 Linear Algebra 1  
or MATH 0540 Linear Algebra With Theory  
or CSCI 0530 Coding the Matrix: An Introduction to Linear Algebra for Computer Science

### Core Courses

MATH 1530 Abstract Algebra 1

Select one of the following series: 2

#### Series A

CSCI 0150 & CSCI 0200 Introduction to Object-Oriented Programming and Computer Science and Program Design with Data Structures and Algorithms

#### Series B

CSCI 0170 & CSCI 0200 Computer Science: An Integrated Introduction and Program Design with Data Structures and Algorithms

#### Series C

CSCI 0190 Accelerated Introduction to Computer Science (and an additional CS course numbered 200 or above not otherwise used to satisfy a concentration requirement; a Foundations course, or a 1000-level CS course)

#### Series D <sup>1</sup>

CSCI 0111 & CSCI 0200 Computing Foundations: Data and Program Design with Data Structures and Algorithms

Foundations Courses: Two courses, touching two different Foundations areas: 2

#### a. Algorithms/Theory Foundations

CSCI 0500 Data Structures, Algorithms, and Intractability: An Introduction

#### b. AI/Machine Learning/Data Science Foundations.

CSCI 0410 Foundations of AI

#### c. Systems Foundations. Concentration credit for only one of 300/330

CSCI 0300 Fundamentals of Computer Systems  
or CSCI 0320 Introduction to Software Engineering  
or CSCI 0330 Introduction to Computer Systems

Three 1000-level Mathematics courses 3

Three courses in Computer Science at the 1000-level or higher. One of these can be an additional 100-level Foundations course or a CSCI non-technical course, as defined by the concentration handbook. 3

Three additional courses different from any of the above chosen from Mathematics, Computer Science, Applied Mathematics, or related areas <sup>4</sup> 3

A capstone course in Computer Science or Mathematics <sup>5</sup> 1

**Total Credits** 19

<sup>1</sup> Students wishing to go directly from CSCI 0111 to CSCI 0200 will need to successfully complete additional exercises to receive an instructor override code for CSCI 0200.

<sup>2</sup> These must be CSCI courses at the 1000-level or higher. Credit will only be given for one of CSCI 410, CSCI 1410, CSCI 1411, and only one credit for CSCI 300, CSCI 330. See current handbook for

list. <https://cs.brown.edu/degrees/undergrad/concentrating-in-cs/concentration-handbook/>

<sup>3</sup> Concentration credit will be given for only one of APMA 1650, APMA 1655, and CSCI 1450. These must be approved by a concentration advisor.

<sup>4</sup> A one-semester course, 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. A senior thesis which involves two semesters of work may count as a Capstone.

Course-based capstones are currently only available through CS. Approved capstone courses and instructions may be found in the CS concentration handbook (<https://cs.brown.edu/degrees/undergrad/concentrating-in-cs/concentration-handbook/>)

## Requirements for the Professional Track of the Sc.B. degree.

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

<https://bulletin.brown.edu/undergradprotrack/>

## Mathematics-Economics Concentration Requirements

The Mathematics Economics concentration is designed to give a background in economic theory plus the mathematical tools needed to analyze and develop additional theoretical constructions. The emphasis is on the abstract theory itself. Students may choose either the standard or the professional track, both award a Bachelor of Arts degree. If you are interested in declaring a concentration in Mathematics Economics, please refer to this page for more information regarding the process.

### Standard Mathematics-Economics Concentration Honors:

#### Economics

|   |   |   |
|---|---|---|
| ECON 1130   | Intermediate Microeconomics (Mathematical) <sup>1</sup>               | 1 |
| ECON 1210   | Intermediate Macroeconomics   | 1 |
| ECON 1630   | Mathematical Econometrics I   | 1 |
| Two courses from the "mathematical-economics" group: <sup>2</sup> |   | 2 |
| ECON 1170   | Welfare Economics and Social Choice Theory                            |   |
| ECON 1225   | Advanced Macroeconomics: Monetary, Fiscal, and Stabilization Policies |   |
| ECON 1255   | Unemployment: Models and Policies                                     |   |
| ECON 1470   | Bargaining Theory and Applications                                    |   |
| ECON 1490   | Designing Internet Marketplaces                                       |   |
| ECON 1545   | Topics in Macroeconomics, Development and International Economics     |   |
| ECON 1560   | Economic Growth   |   |
| ECON 1640   | Mathematical Econometrics II  |   |
| ECON 1660   | Big Data  |   |
| ECON 1670   | Advanced Topics in Econometrics                                       |   |
| ECON 1680   | Machine Learning, Text Analysis, and Economics                        |   |
| ECON 1750   | Investments II  |   |
| ECON 1770   | Crisis Economics  |   |
| ECON 1805   | Experimental and Behavioral Economics                                 |   |
| ECON 1820   | Theory of Behavioral Economics  |   |

|   |  |           |
|---|--|-----------|
| ECON 1860   | The Theory of General Equilibrium                        |           |
| ECON 1870   | Game Theory and Applications to Economics                |           |
| One course from the "data methods" group: <sup>2</sup>  |  | 1         |
| ECON 1301   | Economics of Education I                                 |           |
| ECON 1310   | Labor Economics  |           |
| ECON 1315   | Health, Education, and Social Policy                     |           |
| ECON 1330   | Gender and Development                                   |           |
| ECON 1340   | Economics of Global Warming                              |           |
| ECON 1345   | Climate Change and the Commons                           |           |
| ECON 1355   | Environmental Issues in Development Economics            |           |
| ECON 1360   | Health Economics   |           |
| ECON 1375   | Inequality of Opportunity in the US                      |           |
| ECON 1385   | Intergenerational Poverty in America                     |           |
| ECON 1400   | The Economics of Mass Media                              |           |
| ECON 1410   | Urban Economics  |           |
| ECON 1430   | The Economics of Social Policy                           |           |
| ECON 1510   | Economic Development                                     |           |
| ECON 1530   | Health, Hunger and the Household in Developing Countries |           |
| ECON 1629   | Applied Research Methods for Economists                  |           |
| ECON 1640   | Mathematical Econometrics II                             |           |
| ECON 1660   | Big Data   |           |
| ECON 1670   | Advanced Topics in Econometrics                          |           |
| ECON 1680   | Machine Learning, Text Analysis, and Economics           |           |
| ECON 1825   | Behavioral Economics and Public Policy                   |           |
| ECON 1830   | Behavioral Finance                                       |           |
| Two additional 1000-level economics courses <sup>3</sup>  |  | 2         |
| <b>Mathematics</b>  |  |           |
| Calculus: MATH 0180 or higher   |  | 1         |
| Linear Algebra - one of the following:  |  | 1         |
| MATH 0520   | Linear Algebra   |           |
| MATH 0540   | Linear Algebra With Theory                               |           |
| Probability Theory - one of the following:  |  | 1         |
| MATH 1210   | Probability (Formerly MATH 1610)                         |           |
| MATH 1620   | Mathematical Statistics                                  |           |
| APMA 1650   | Introduction to Probability and Statistics with Calculus |           |
| Analysis - one of the following:  |  | 1         |
| MATH 1010   | Analysis: Functions of One Variable                      |           |
| MATH 1630   | Real Analysis I (Formerly MATH 1130)                     |           |
| MATH 1640   | Real Analysis II (Formerly MATH 1140)                    |           |
| Differential Equations - one of the following:  |  | 1         |
| MATH 1110   | Ordinary Differential Equations                          |           |
| MATH 1120   | Partial Differential Equations                           |           |
| One additional course from the Probability, Analysis, and Differential Equations courses listed above |  | 1         |
| <b>Total Credits</b>  |  | <b>14</b> |

<sup>1</sup> Or ECON 1110 with permission. For students matriculating at Brown in Fall 2021 or later, note that if ECON 1110 is used, then one additional course from the mathematical-economics group will be required

<sup>2</sup> No course may be "double-counted" to satisfy both the mathematical-economics and data methods requirement.

<sup>3</sup> Students may apply, at most, one Economics course whose number is in the range of 1000 to 1099 toward the concentration. Note that ECON 1620, ECON 1960, and ECON 1970 (independent study) cannot be used for concentration credit. However, ECON 1620 and ECON 1960

can be used for university credit and up to two 1970s may be used for university credit.

<sup>4</sup> MATH 1630 (formerly MATH 1130) is a prerequisite for MATH 1640 (formerly MATH 1140).

## Honors

Students who meet stated requirements are eligible to write an honors thesis in their senior year. Students should consult the listed honors requirements of whichever of the two departments their primary thesis advisor belongs to, at the respective departments' websites.

## Professional Track:

The requirements for all undergraduate professional tracks within concentrations are standardized and additional information can be found here:

<https://bulletin.brown.edu/undergradprotrack/>

## Mathematics Graduate Program

The Math Department PhD program is intended for students with a solid background in undergraduate mathematics and a strong interest in research. Most of our students intend to pursue academic careers or find other kinds of positions, for example in industry or finance.

We aim to provide a supportive environment for teaching, learning, and creating mathematics. The relatively small size (about 40+ graduate students and 25+ faculty and postdocs) allows for close contact with faculty and a sense of community. The program is flexible enough to accommodate a range of levels of preparation. More than 85% of students admitted receive their PhD.

For more information on admission and program requirements, please visit the following website:

<https://www.brown.edu/academics/math/graduate> (<https://www.brown.edu/academics/math/graduate/>)

## 5th Year Masters Program

The program is only available as a 5th year masters program and only open to current Brown undergraduates, who must apply before graduating.

To earn a fifth year masters degree, the student must complete eight 2000-level courses with a grade of B or higher.

Students must complete at least three of the following "core" courses, which are offered in the fall.

|           |                           |   |
|-----------|---------------------------|---|
| MATH 2110 | Introduction to Manifolds | 1 |
| MATH 2210 | Real Function Theory      | 1 |
| MATH 2250 | Complex Function Theory   | 1 |
| MATH 2410 | Topology                  | 1 |
| MATH 2510 | Algebra                   | 1 |

Other eligible courses, beyond the minimum three core courses from above, are the following spring term courses:

|           |                         |   |
|-----------|-------------------------|---|
| MATH 2010 | Differential Geometry   | 1 |
| MATH 2220 | Real Function Theory    | 1 |
| MATH 2260 | Complex Function Theory | 1 |
| MATH 2420 | Algebraic Topology      | 1 |
| MATH 2520 | Algebra                 | 1 |

There are also the below advanced graduate courses. In order for one of these to be counted toward the fifth year Master's, it must be taken for "qualifying credit". This means that the student must notify the instructor in advance that he/she desires to earn qualifying credit, and then the instructor will assign suitable written work or an oral presentation.

|           |                                |   |
|-----------|--------------------------------|---|
| MATH 2050 | Algebraic Geometry             | 1 |
| MATH 2060 | Algebraic Geometry             | 1 |
| MATH 2370 | Partial Differential Equations | 1 |
| MATH 2380 | Partial Differential Equations | 1 |
| MATH 2530 | Number Theory                  | 1 |

|           |               |   |
|-----------|---------------|---|
| MATH 2540 | Number Theory | 1 |
| MATH 2630 | Probability   | 1 |
| MATH 2640 | Probability   | 1 |

A course in the 2710-2720 Topics Series

With permission of the Director of Graduate Studies, up to two graduate level courses in Applied Mathematics may also be counted.

A Master's thesis is not required, nor are there any additional exams beyond the final exams for each of the courses.

Up to two of the eight courses may be graduate-level Mathematics courses which the student has already taken as an undergraduate.

## Courses

### MATH 0010A. First Year Seminar: A Taste of the Infinite.

The concept of infinity occurs in many disciplines - philosophy, mathematics, physics, religion, art, and so on. This class will focus on the mathematical aspects of infinity, surveying some of the ways that the infinite arises in mathematics. Topics will include: the sizes of infinity, rates of growth, computational complexity, construction of the real numbers, the notion of compactness, geometric spaces, transcendental numbers, and fractal sets. I will not assume any prior knowledge of mathematics beyond a good grounding in high school algebra and geometry.

### MATH 0010B. Exploring the Fourth Dimension.

This interdisciplinary seminar explores all the mathematics students have seen or ever will see, concentrating on an engaging topic that begins with elementary geometry and branches out to literature, history, philosophy, and art as well as physics and other sciences. Guideposts to the fourth dimension include Salvador Dali's *Corpus Hypercubicus*, Edwin Abbott's *Flatland*, and Jeff Weeks' *The Shape of Space*. Students will investigate new mathematical topics such as combinatorics, regular polytopes, topology, and non-Euclidean geometry. Although students will use computers for visualization, no computer experience is required. There are no specific mathematical prerequisites except curiosity and a willingness to participate actively. Students considering concentrations in humanities, social sciences, and the arts are especially invited to this first-year seminar. Enrollment limited to 19 first year students.

### MATH 0010C. From 'Flatland' to the Fourth Dimension.

No description available. Enrollment limited to 15 first year students. Instructor permission required, after initial placement of students.

### MATH 0050. Analytic Geometry and Calculus.

MATH 0050 and 0060 provide a slower-paced introduction to calculus for students who require additional preparation. Presents the same calculus topics as MATH 0090, together with a review of the necessary precalculus topics. Students successfully completing this sequence are prepared for MATH 0100. S/NC only.

|      |          |     |       |     |                 |                  |
|------|----------|-----|-------|-----|-----------------|------------------|
| Fall | MATH0050 | S01 | 10108 | TTh | 10:30-11:50(13) | 'To Be Arranged' |
| Fall | MATH0050 | C01 | 17692 | Th  | 10:30-11:20     | 'To Be Arranged' |

### MATH 0060. Analytic Geometry and Calculus.

A slower-paced introduction to calculus for students who require additional preparation. Presents the same calculus topics as MATH 0090, together with a review of the necessary precalculus topics. Students successfully completing this sequence are prepared for MATH 0100. Prerequisite: MATH 0050 or written permission. May not be taken for credit in addition to MATH 0070 or MATH 0090. S/NC only.

|     |          |     |       |     |                 |                  |
|-----|----------|-----|-------|-----|-----------------|------------------|
| Spr | MATH0060 | S01 | 20098 | MWF | 12:00-12:50(01) | 'To Be Arranged' |
| Spr | MATH0060 | C01 | 25893 | T   | 10:30-11:20     | 'To Be Arranged' |

### MATH 0070. Calculus with Applications to Social Science.

A survey of calculus for students who wish to learn the basics of calculus for application to social sciences or for cultural appreciation as part of a broader education. Topics include functions, equations, graphs, exponentials and logarithms, and differentiation and integration; applications such as marginal analysis, growth and decay, optimization, and elementary differential equations. May not be taken for credit in addition to MATH 0060 or MATH 0090. S/NC only.

### MATH 0081. Math Teaching Fellows Program.

The Math Teaching Fellows Program is a semester-long certificate program that provides UTAs with the skills and knowledge required to be an effective UTA in the Math Department. Admission into the program is by application only; participants will hold a UTA appointment in a Mathematics course approved by the Teaching Fellows Coordinators and must therefore be eligible for student employment at Brown during the term. Participants should have completed at least one of Math 0100, 0180, 0190, 0200, 0350, 0520, 0540.

|      |          |     |       |          |          |
|------|----------|-----|-------|----------|----------|
| Fall | MATH0081 | S01 | 18837 | Arranged | (Y. Hsu) |
|------|----------|-----|-------|----------|----------|

### MATH 0090. Single Variable Calculus, Part I.

An intensive course in calculus of one variable including limits, differentiation, maxima and minima, the chain rule, rational functions, trigonometric functions, and exponential functions. Introduction to integration with applications to area and volumes of revolution. MATH 0090 and MATH 0100 or the equivalent are recommended for all students intending to concentrate in the sciences or mathematics. May not be taken for credit in addition to MATH 0060 or MATH 0070. S/NC only.

|      |          |     |       |     |                 |                  |
|------|----------|-----|-------|-----|-----------------|------------------|
| Fall | MATH0090 | S01 | 10110 | MWF | 9:00-9:50(09)   | 'To Be Arranged' |
| Fall | MATH0090 | S02 | 10111 | MWF | 11:00-11:50(16) | (D. Katz)        |
| Fall | MATH0090 | S03 | 10112 | MWF | 12:00-12:50(15) | 'To Be Arranged' |
| Fall | MATH0090 | S04 | 10113 | TTh | 1:00-2:20(06)   | 'To Be Arranged' |
| Fall | MATH0090 | S05 | 10114 | MWF | 2:00-2:50(01)   | 'To Be Arranged' |
| Fall | MATH0090 | C01 | 17694 | Th  | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0090 | C02 | 17695 | Th  | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0090 | C03 | 17696 | Th  | 10:30-11:50     | 'To Be Arranged' |
| Fall | MATH0090 | C04 | 17697 | Th  | 10:30-11:50     | 'To Be Arranged' |
| Fall | MATH0090 | C05 | 17698 | Th  | 1:00-2:20       | 'To Be Arranged' |
| Fall | MATH0090 | C06 | 17699 | Th  | 1:00-2:20       | 'To Be Arranged' |
| Fall | MATH0090 | C07 | 17700 | Th  | 2:30-3:50       | 'To Be Arranged' |
| Fall | MATH0090 | C08 | 17701 | Th  | 2:30-3:50       | 'To Be Arranged' |
| Fall | MATH0090 | C09 | 17702 | Th  | 6:40-8:00PM     | 'To Be Arranged' |
| Fall | MATH0090 | C10 | 17703 | Th  | 6:40-8:00PM     | 'To Be Arranged' |
| Spr  | MATH0090 | S01 | 20099 | TTh | 9:00-10:20(05)  | (P. Zenz)        |
| Spr  | MATH0090 | S02 | 20100 | TTh | 1:00-2:20(08)   | (Y. Hsu)         |
| Spr  | MATH0090 | C01 | 25894 | T   | 9:00-10:20      | 'To Be Arranged' |
| Spr  | MATH0090 | C02 | 25895 | T   | 9:00-10:20      | 'To Be Arranged' |
| Spr  | MATH0090 | C03 | 25896 | T   | 6:40-8:00PM     | 'To Be Arranged' |
| Spr  | MATH0090 | C04 | 25897 | T   | 2:30-3:50       | 'To Be Arranged' |



**MATH 0100. Single Variable Calculus, Part II.**

A continuation of the material of MATH 90 including further development of techniques of integration. Other topics covered are infinite series, power series, Taylor's formula, polar coordinates, parametric equations, introduction to differential equations, and numerical methods. MATH 90 and 100 or the equivalent are recommended for all students intending to concentrate in mathematics or the sciences. MATH 100 may not be taken in addition to MATH 170 or MATH 190.

|      |          |     |       |          |                 |                  |
|------|----------|-----|-------|----------|-----------------|------------------|
| Fall | MATH0100 | S01 | 10115 | Arranged |                 | (Y. Hsu)         |
| Fall | MATH0100 | C01 | 17704 | T        | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0100 | C02 | 17705 | T        | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0100 | C03 | 17706 | T        | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0100 | C04 | 17707 | T        | 10:30-11:50     | 'To Be Arranged' |
| Fall | MATH0100 | C05 | 17708 | T        | 10:30-11:50     | 'To Be Arranged' |
| Fall | MATH0100 | C06 | 17709 | T        | 9:00-10:20      | 'To Be Arranged' |
| Fall | MATH0100 | C07 | 17710 | T        | 1:00-2:20       | 'To Be Arranged' |
| Fall | MATH0100 | C08 | 17711 | T        | 1:00-2:20       | 'To Be Arranged' |
| Fall | MATH0100 | C09 | 17712 | T        | 2:30-3:50       | 'To Be Arranged' |
| Fall | MATH0100 | C10 | 17713 | T        | 2:30-3:50       | 'To Be Arranged' |
| Fall | MATH0100 | C11 | 17714 | T        | 6:40-8:00PM     | 'To Be Arranged' |
| Fall | MATH0100 | C12 | 17715 | T        | 6:40-8:00PM     | 'To Be Arranged' |
| Fall | MATH0100 | C13 | 17716 | T        | 6:40-8:00PM     | 'To Be Arranged' |
| Fall | MATH0100 | C14 | 17717 | T        | 2:30-3:50       | 'To Be Arranged' |
| Spr  | MATH0100 | S01 | 20101 | MWF      | 9:00-9:50(02)   | 'To Be Arranged' |
| Spr  | MATH0100 | S02 | 20102 | MWF      | 12:00-12:50(01) | (Y. Lin)         |
| Spr  | MATH0100 | S03 | 20103 | TTh      | 10:30-11:50(09) | (L. Keenan)      |
| Spr  | MATH0100 | S04 | 20104 | TTh      | 1:00-2:20(08)   | (L. Keenan)      |
| Spr  | MATH0100 | C01 | 25898 | Th       | 9:00-10:20      | 'To Be Arranged' |
| Spr  | MATH0100 | C02 | 25899 | Th       | 9:00-10:20      | 'To Be Arranged' |
| Spr  | MATH0100 | C03 | 25900 | Th       | 10:30-11:50     | 'To Be Arranged' |
| Spr  | MATH0100 | C04 | 25901 | Th       | 2:30-3:50       | 'To Be Arranged' |
| Spr  | MATH0100 | C05 | 25902 | Th       | 1:00-2:20       | 'To Be Arranged' |
| Spr  | MATH0100 | C06 | 25903 | Th       | 1:00-2:20       | 'To Be Arranged' |
| Spr  | MATH0100 | C07 | 25904 | Th       | 2:30-3:50       | 'To Be Arranged' |
| Spr  | MATH0100 | C08 | 25905 | Th       | 2:30-3:50       | 'To Be Arranged' |
| Spr  | MATH0100 | C09 | 25906 | Th       | 6:40-8:00PM     | 'To Be Arranged' |
| Spr  | MATH0100 | C10 | 25907 | Th       | 6:40-8:00PM     | 'To Be Arranged' |

**MATH 0170. Single Variable Calculus, Part II (Accelerated).**

This course, which covers roughly the same material and has the same prerequisites as MATH 100, covers integration techniques, sequences and series, parametric and polar curves, and differential equations of first and second order. Topics will generally include more depth and detail than in MATH 100. MATH 170 may not be taken in addition to MATH 100 or MATH 190.

**MATH 0180. Multivariable Calculus.**

Three-dimensional analytic geometry. Differential and integral calculus of functions of two or three variables: partial derivatives, multiple integrals, Green's Theorem, Stokes' theorem, and the divergence theorem. Prerequisite: MATH 100, MATH 170, or MATH 190, or advanced placement or written permission. [MATH 180 may not be taken in addition to MATH 200 or MATH 350.]

|      |          |     |       |     |                 |                  |
|------|----------|-----|-------|-----|-----------------|------------------|
| Fall | MATH0180 | S01 | 10120 | MWF | 10:00-10:50(14) | (D. Katz)        |
| Fall | MATH0180 | S02 | 10121 | MWF | 12:00-12:50(15) | (Z. Wei)         |
| Fall | MATH0180 | S03 | 10122 | MWF | 1:00-1:50(08)   | 'To Be Arranged' |
| Fall | MATH0180 | C01 | 17718 | Th  | 9:00-9:50       | 'To Be Arranged' |
| Fall | MATH0180 | C02 | 17719 | Th  | 1:00-1:50       | 'To Be Arranged' |
| Fall | MATH0180 | C03 | 17720 | Th  | 12:00-12:50     | 'To Be Arranged' |
| Fall | MATH0180 | C04 | 17721 | Th  | 12:00-12:50     | 'To Be Arranged' |
| Fall | MATH0180 | C05 | 17722 | Th  | 2:30-3:20       | 'To Be Arranged' |
| Fall | MATH0180 | C06 | 17723 | Th  | 6:40-7:30       | 'To Be Arranged' |
| Spr  | MATH0180 | S01 | 20105 | MWF | 11:00-11:50(04) | (D. Katz)        |
| Spr  | MATH0180 | S02 | 20106 | MWF | 12:00-12:50(01) | 'To Be Arranged' |
| Spr  | MATH0180 | S03 | 20107 | MWF | 1:00-1:50(06)   | 'To Be Arranged' |
| Spr  | MATH0180 | C01 | 25910 | Th  | 9:00-9:50       | 'To Be Arranged' |
| Spr  | MATH0180 | C02 | 25911 | Th  | 10:30-11:20     | 'To Be Arranged' |
| Spr  | MATH0180 | C03 | 25912 | Th  | 12:00-12:50     | 'To Be Arranged' |
| Spr  | MATH0180 | C04 | 25913 | Th  | 12:00-12:50     | 'To Be Arranged' |
| Spr  | MATH0180 | C05 | 25914 | Th  | 2:30-3:20       | 'To Be Arranged' |
| Spr  | MATH0180 | C06 | 25915 | Th  | 6:40-7:30       | 'To Be Arranged' |

**MATH 0190. Single Variable Calculus, Part II (Physics/Engineering).**

This course, which covers roughly the same material and has the same prerequisites as MATH 100, is intended for students with a special interest in physics or engineering. The main topics are: applications and techniques of integration; sequences, series, and power series methods; parametric equations and polar coordinates; additional topics at instructor's discretion. MATH 190 may not be taken in addition to MATH 100 or MATH 170.

|      |          |     |       |     |               |                  |
|------|----------|-----|-------|-----|---------------|------------------|
| Fall | MATH0190 | S01 | 10123 | MWF | 9:00-9:50(09) | 'To Be Arranged' |
| Fall | MATH0190 | S02 | 10124 | TTh | 2:30-3:50(12) | (Y. Lin)         |

**MATH 0200. Multivariable Calculus (Physics/Engineering).**

This course, which covers roughly the same material as MATH 180, is intended for students with a special interest in physics or engineering. The main topics are: geometry of three-dimensional space; partial derivatives; Lagrange multipliers; double, surface, and triple integrals; vector analysis; Stokes' theorem and the divergence theorem, with applications to electrostatics and fluid flow. Prerequisite: MATH 100, MATH 170, or MATH 190, or advanced placement or written permission. [MATH 200 may not be taken in addition to MATH 180 or MATH 350.]

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|------|----------|-----|-------|-----|-----------------|------------------|
| Fall | MATH0200 | S01 | 10125 | TTh | 9:00-10:20(05)  | 'To Be Arranged' |
| Fall | MATH0200 | S02 | 10126 | MWF | 12:00-12:50(15) | 'To Be Arranged' |
| Fall | MATH0200 | S03 | 10127 | TTh | 2:30-3:50(12)   | (Y. Hsu)         |
| Fall | MATH0200 | C01 | 17724 | T   | 10:30-11:20     | 'To Be Arranged' |
| Fall | MATH0200 | C02 | 17725 | T   | 12:00-12:50     | 'To Be Arranged' |
| Fall | MATH0200 | C03 | 17726 | T   | 12:00-12:50     | 'To Be Arranged' |
| Fall | MATH0200 | C04 | 17727 | T   | 1:00-1:50       | 'To Be Arranged' |
| Fall | MATH0200 | C05 | 17728 | T   | 2:30-3:20       | 'To Be Arranged' |
| Fall | MATH0200 | C06 | 17729 | T   | 6:40-7:30       | 'To Be Arranged' |
| Spr  | MATH0200 | S01 | 20108 | TTh | 9:00-10:20(05)  | 'To Be Arranged' |
| Spr  | MATH0200 | S02 | 20109 | TTh | 10:30-11:50(09) | (B. Dees)        |
| Spr  | MATH0200 | S03 | 20110 | TTh | 2:30-3:50(11)   | (Y. Hsu)         |
| Spr  | MATH0200 | C01 | 25916 | T   | 9:00-9:50       | 'To Be Arranged' |
| Spr  | MATH0200 | C02 | 25917 | T   | 10:30-11:50     | 'To Be Arranged' |
| Spr  | MATH0200 | C03 | 25918 | T   | 12:00-12:50     | 'To Be Arranged' |
| Spr  | MATH0200 | C04 | 25919 | T   | 1:00-1:50       | 'To Be Arranged' |
| Spr  | MATH0200 | C05 | 25920 | T   | 2:30-3:20       | 'To Be Arranged' |
| Spr  | MATH0200 | C06 | 25921 | T   | 6:40-7:30       | 'To Be Arranged' |

**MATH 0350. Multivariable Calculus With Theory.**

This course provides a rigorous treatment of multivariable calculus. Topics covered include vector analysis, partial differentiation, multiple integration, line integrals, Green's theorem, Stokes' theorem, and the divergence theorem. MATH 0350 covers the same material as MATH 0180, but with more emphasis on theory and on understanding proofs. Prerequisites: MATH 0100, MATH 0170, or MATH 0190, or advanced placement or written permission. [MATH 0350 may not be taken in addition to MATH 0180 or MATH 0200.]

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| Fall | MATH0350 | S01 | 10128 | TTh | 1:00-2:20(06) | (B. Dees) |
|------|----------|-----|-------|-----|---------------|-----------|

**MATH 0420. Introduction to Number Theory.**

An overview of one of the most beautiful areas of mathematics. Ideal for any student who wants a taste of mathematics outside of, or in addition to, the calculus sequence. Topics include: prime numbers, congruences, quadratic reciprocity, sums of squares, Diophantine equations, and, as time permits, such topics as cryptography and continued fractions. No prerequisites.

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| Spr | MATH0420 | S01 | 25922 | MWF | 2:00-2:50(07) | (Z. Wei) |
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**MATH 0520. Linear Algebra.**

A first course in linear algebra designed to develop students' problem solving skills, mathematical writing skills, and gain facility with the applications and theory of linear algebra. Topics will include: vector spaces, linear transformations, matrices, systems of linear equations, bases, eigenvalues, and additional topics at instructor's discretion. Applications may include differential equations, difference equations, least squares approximations, and models in economics and in biological and physical sciences. MATH 0520 or MATH 0540 is a prerequisite for all 1000-level courses in Mathematics except MATH 1260 or MATH 1610. Recommended prerequisite: MATH 0100 or equivalent. May not be taken in addition to MATH 0540.

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|------|----------|-----|-------|-----|-----------------|------------------|
| Fall | MATH0520 | S01 | 10129 | TTh | 10:30-11:50(13) | (E. Dlugie)      |
| Fall | MATH0520 | S02 | 10130 | MWF | 11:00-11:50(16) | 'To Be Arranged' |
| Fall | MATH0520 | S03 | 10131 | MWF | 12:00-12:50(15) | 'To Be Arranged' |
| Fall | MATH0520 | S04 | 10132 | MWF | 1:00-1:50(08)   | 'To Be Arranged' |
| Fall | MATH0520 | S05 | 10133 | MWF | 9:00-9:50(09)   | 'To Be Arranged' |
| Fall | MATH0520 | S06 | 17731 | TTh | 1:00-2:20(06)   | (E. Dlugie)      |
| Fall | MATH0520 | S07 | 17732 | TTh | 9:00-10:20(05)  | 'To Be Arranged' |
| Spr  | MATH0520 | S01 | 20111 | MWF | 9:00-9:50(02)   | (M. Ulmer)       |
| Spr  | MATH0520 | S02 | 20112 | MWF | 2:00-2:50(07)   | 'To Be Arranged' |
| Spr  | MATH0520 | S03 | 20113 | MWF | 11:00-11:50(04) | 'To Be Arranged' |
| Spr  | MATH0520 | S04 | 20114 | MWF | 12:00-12:50(01) | 'To Be Arranged' |
| Spr  | MATH0520 | S05 | 20115 | MWF | 1:00-1:50(06)   | (W. Lim)         |
| Spr  | MATH0520 | S06 | 20116 | TTh | 9:00-10:20(05)  | 'To Be Arranged' |
| Spr  | MATH0520 | S07 | 20117 | TTh | 10:30-11:50(09) | (E. Jovinelly)   |

**MATH 0540. Linear Algebra With Theory.**

This course provides a rigorous introduction to the theory of linear algebra. Topics covered include: matrices, linear equations, determinants, and eigenvalues; vector spaces and linear transformations; inner products; Hermitian, orthogonal, and unitary matrices; and Jordan normal form. MATH 540 provides a more theoretical treatment of the topics in MATH 520, and students will have opportunities during the course to develop proof-writing skills. Recommended prerequisite: MATH 100, MATH 170, or MATH 190. [MATH 540 may not be taken in addition to MATH 520.]

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| Fall | MATH0540 | S01 | 10134 | TTh | 10:30-11:50(13) | (S. Hashimoto) |
| Fall | MATH0540 | S02 | 17733 | TTh | 2:30-3:50(12)   | (S. Hashimoto) |
| Spr  | MATH0540 | S01 | 20118 | MWF | 10:00-10:50(03) | (J. Silverman) |

**MATH 0550. Problems from the History of Mathematics.**

This course presents a history of mathematics through the lens of famous mathematical problems. Beginning in Ancient Greece and Babylon and continuing to the present, we discuss the problems that shaped the development of modern mathematics. Sample topics include the impossible constructions of Ancient Greece, paradoxes from the birth of calculus, the problems that gave rise to graph theory, and the rise of computer-assisted proofs.

**MATH 0580. Mathematical Forms in Architecture.**

This project will explore and advance innovative applications of mathematics to architecture using computational methods. Historically, architecture has been guided primarily by an intuitive creative process. In contrast to the end-results of intuitive design, many "optimal" forms--i.e. geometric shapes and configurations that satisfy extremal conditions--are unique because they are the result of systematic physical experiments or explicit mathematical study in addition to imaginative input. Classic questions for which human intuition alone has been incapable of finding a solution include: What is the exact shape of the optimal arch?, or What is the shape of a child's slide that minimizes the time of travel? The use of computational methods to generate solutions to these problems will be made considerably simpler via optimization libraries in Mathematica. The application to architecture in this project will provide students a unique concrete backdrop to visualize solutions to these problems.

**MATH 0750. Introduction to Higher Mathematics.**

This semester-long class will expose students to several fundamental areas of mathematics. It will be team taught by three members of the faculty. Topics, which will vary from year to year, will be chosen from logic and set theory, number theory, abstract algebra, combinatorics and graph theory, analysis, and geometry. Approximately 4 weeks will be devoted to each of the selected topics.

**MATH 0760. Introduction to Higher Mathematics.**

This year-long class will expose students to six fundamental areas of mathematics. It will be team taught by six members of the faculty. Fall topics will include logic, combinatorics, and analysis. Spring topics will include number theory, algebra, and geometry. Approximately 4 weeks will be devoted to each topic.

**MATH 1000. The Art of Writing Mathematics.**

MATH 1001 is an introduction to proof-writing designed to prepare students for further exploration of rigorous mathematics. Students will be trained to identify and employ a variety of proof-techniques such as direct proof, proof by contradiction, proof by induction, and proof by cases, to name a few. Mathematical topics covered include samplings of set theory, logic, and number theory, with additional topics chosen at the instructors discretion if time permits. Recommended Prerequisites: MATH 0520, MATH 0540, MATH 0100, MATH 0190, MATH 0180, MATH 0200, or MATH 0350. Students with little proof writing experience are encouraged to take MATH 1001 prior to taking, or concurrently with, other 1000-level Mathematics courses.

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| Spr | MATH1000 | S01 | 25923 | TTh | 2:30-3:50(11) | (E. Dlugie) |
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**MATH 1010. Analysis: Functions of One Variable.**

Completeness properties of the real number system, topology of the real line. Proof of basic theorems in calculus, infinite series. Topics selected from ordinary differential equations. Fourier series, Gamma functions, and the topology of Euclidean plane and 3-space. Prerequisite: MATH 0180, 0200, or 0350. MATH 0520 or 0540 may be taken concurrently. Most students are advised to take MATH 1010 before MATH 1630.

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| Fall | MATH1010 | S01 | 17734 | TTh | 1:00-2:20(06)   | (R. Schwartz) |
| Spr  | MATH1010 | S01 | 20120 | MWF | 11:00-11:50(04) | (M. Ulmer)    |
| Spr  | MATH1010 | S02 | 25924 | TTh | 2:30-3:50(11)   | (B. Dees)     |

**MATH 1030. Graph Theory.**

This course covers important material about graph theory, such as spanning trees, network flow problems, matching problems, coloring problems, planarity, Cayley graphs, spectral theory on graphs, and Ramsey Theory. The emphasis will be on a combination of theory and algorithms. Depending on the instructor, connections to such fields as combinatorics, geometry, or computer science might be emphasized. Prerequisite: MATH 0180, 0200 or 0350 and MATH 0520 or 0540 are recommended.

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| Spr | MATH1030 | S01 | 25925 | MWF | 9:00-9:50(02) | (B. Tshishiku) |
| Spr | MATH1030 | S02 | 25926 | TTh | 1:00-2:20(08) | (E. Jovinelly) |

**MATH 1040. Fundamental Problems of Geometry.**

This class discusses geometry from a modern perspective. Topics include hyperbolic, projective, conformal, and affine geometry, and various theorems and structures built out of them. Prerequisite: MA 0520, MA 0540, or permission of the instructor.

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| Spr | MATH1040 | S01 | 20121 | MWF | 10:00-10:50(03) | (W. Lim) |
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**MATH 1060. Differential Geometry.**

The study of curves and surfaces in 2- and 3-dimensional Euclidean space using the techniques of differential and integral calculus and linear algebra. Topics include curvature and torsion of curves, Frenet-Serret frames, global properties of closed curves, intrinsic and extrinsic properties of surfaces, Gaussian curvature and mean curvature, geodesics, minimal surfaces, and the Gauss-Bonnet theorem.

Fall MATH1060 S01 10137 TTh 9:00-10:20(05) (B. Tshishiku)

**MATH 1080. Cryptography.**

This course focuses on the mathematics underlying public key cryptosystems, digital signatures, and other topics in cryptography. A sampling of mathematical topics, such as groups, rings, fields, number theory, probability, complexity theory, elliptic curves, and lattices, will be introduced and applied to cryptography. No prior knowledge of these topics is assumed, nor is prior programming experience needed; any programming knowledge required will be covered in class.

Spr MATH1080 S01 25927 MWF 9:00-9:50(02) (I. Vogt)

Spr MATH1080 S02 25928 TTh 1:00-2:20(08) (P. Zenz)

**MATH 1110. Ordinary Differential Equations.**

Ordinary differential equations, including existence and uniqueness theorems and the theory of linear systems. Topics may also include stability theory, the study of singularities, and boundary value problems.

Fall MATH1110 S01 10138 MWF 11:00-11:50(16) (W. Lim)

**MATH 1120. Partial Differential Equations.**

The wave equation, the heat equation, Laplace's equation, and other classical equations of mathematical physics and their generalizations, discussion of well-posedness problems. The method of characteristics, initial and boundary conditions, separation of variables, solutions in series of eigenfunctions, Fourier series, maximum principles, Green's identities and Green's functions.

Spr MATH1120 S01 20122 MWF 11:00-11:50(04) (B. Pausader)

**MATH 1150. Machine Learning for Scientific Modeling: Data-Driven Discovery of Differential Equations.**

This junior/senior level course will explore the use of Machine Learning to automate the discovery and calibration of models involving differential equations directly from data. After introducing the basic machine learning tools (Gaussian Processes and Neural Networks) we will see how they can be combined with ODE and PDE computational methods to generate models in physics, medicine, and finance. The course will progress to a survey of recent research works on the topic. No prior knowledge of machine learning is required.

**MATH 1210. Probability.**

Basic probability theory including random variables, distribution functions, independence, expectation, variance, and conditional expectation. Classical examples of probability density and mass functions (binomial, geometric, normal, exponential) and their applications. Stochastic processes including discrete and continuous time Poisson processes, Markov chains, and Brownian motion.

Fall MATH1210 S01 17736 MWF 2:00-2:50(01) (J. Holmer)

**MATH 1220. Mathematical Statistics.**

Frequentist and Bayesian viewpoints and decision theory principles. Concepts from probability, including the central limit theorem and multivariate normal distributions, and asymptotic estimates. Inferences from independent, identically distributed sampling: point estimation, confidence intervals, and hypothesis testing. Analysis of variance (ANOVA) and generalized linear models of regression.

Spr MATH1220 S01 25931 MWF 1:00-1:50(06) (J. Holmer)

**MATH 1270. Topics in Functional Analysis.**

Infinite-dimensional vector spaces with applications to some or all of the following topics: Fourier series and integrals, distributions, differential equations, integral equations, calculus of variations. Prerequisite: At least one 1000-level course in Mathematics or Applied Mathematics, or permission of the instructor.

Spr MATH1270 S01 25932 MWF 2:00-2:50(07) (N. Wagner)

**MATH 1460. Complex Analysis.**

Examines one of the cornerstones of mathematics. Complex differentiability, Cauchy-Riemann differential equations, contour integration, residue calculus, harmonic functions, geometric properties of complex mappings. Prerequisite: MATH 0180, 0200, or 0350. This course does not require MATH 0520 or 0540.

Fall MATH1460 S01 17737 MWF 9:00-9:50(09) (M. Ulmer)

**MATH 1530. Abstract Algebra.**

A proof-based course that introduces the principles and concepts of modern abstract algebra. Topics will include groups, rings, and fields, with applications to number theory, the theory of equations, and geometry. Previous proof-writing experience is not required. MATH 1530 is required of all students concentrating in mathematics. It is strongly suggested that potential mathematics concentrators make MATH 1530 one of the first thousand level mathematics classes that they take.

Fall MATH1530 S01 10143 MWF 10:00-10:50(14) (I. Vogt)

Fall MATH1530 S02 17738 MWF 11:00-11:50(16) (D. Abramovich)

Spr MATH1530 S01 20125 TTh 9:00-10:20(05) 'To Be Arranged'

Spr MATH1530 S02 25933 TTh 10:30-11:50(09) (S. Hashimoto)

**MATH 1540. Topics in Abstract Algebra.**

Galois theory together with selected topics in algebra. Examples of subjects which have been presented in the past include algebraic curves, group representations, and the advanced theory of equations. Prerequisite: MATH 1530.

Spr MATH1540 S01 20126 MWF 2:00-2:50(07) (D. Abramovich)

**MATH 1560. Number Theory.**

Selected topics in number theory will be investigated. Unique factorization, prime numbers, modular arithmetic, arithmetic functions, quadratic reciprocity, finite fields, and related topics. Prerequisite: MATH 1530 or written permission.

Fall MATH1560 S01 10144 TTh 9:00-10:20(05) 'To Be Arranged'

**MATH 1630. Real Analysis I.**

A rigorous introduction to real analysis, this course treats topics in point set topology, function spaces, differentiability of functions on Euclidean spaces, and Fourier series. Among the many topics and theorems we investigate in detail will be connectedness and compactness, the Arzela-Ascoli theorem, the inverse and implicit function theorems, and  $L^2$  and pointwise convergence of Fourier series. It is recommended that a student take MATH 1010 before attempting MATH 1630.

Fall MATH1630 S01 17739 MWF 1:00-1:50(08) (S. Treil)

**MATH 1640. Real Analysis II.**

A second course in real analysis, in this class we study measure theory and integration as well as Hilbert spaces. Among the many topics we study will be abstract measure and integration theory, Fourier transform, linear functionals and the Riesz representation theorem, compact operators, and the spectral theorem. The course may also include additional material of interest to the students and instructor.

Spr MATH1640 S01 25934 MWF 10:00-10:50(03) (C. Breiner)

**MATH 1710. Topology.**

Topology of Euclidean spaces, winding number and applications, knot theory, fundamental group and covering spaces. Euler characteristic, simplicial complexes, classification of two-dimensional manifolds, vector fields, the Poincaré-Hopf theorem, and introduction to three-dimensional topology. Prerequisites: MATH 0520 or MATH 0540, or instructor permission.

Fall MATH1710 S01 17740 MWF 2:00-2:50(01) (W. Lim)

**MATH 1720. Manifolds.**

Manifolds are a basic concept that unite ideas from linear algebra, multivariable calculus, geometry, and topology. Math and physics research require a familiarity with manifolds. Topics covered include the definition of a smooth manifold either as a smooth subset of  $\mathbb{R}^n$  or as an abstract manifold, coordinating charts, and transition functions. The course will cover concrete examples: e.g. surfaces and 3-manifolds. Other topics include tangent vectors, vector fields, tensors, exterior algebra, differential forms, change of coordinates, Stokes' Theorem and the basics of De Rham cohomology.



**MATH 1810A. Applied Algebraic Topology.**

Topology is a powerful tool for identifying, describing, and characterizing the essential features of functions and spaces. In the recent years some of these methods have been adapted to study the shape of data collected from a range of different fields, including graphics and visualization, computational biology, etc. This course is an introduction to the basic concepts and topological structures behind these developments, focusing on persistent homology and mapper. Projects will involve using these methods to analyze and describe the shape of concrete data sets.

**MATH 1810B. A Second Course in Linear Algebra.**

This is a course in linear algebra for students who have had a standard first course (vector space, linear map, characteristic polynomial). We'll emphasize coordinate-free constructions and universal properties as much as possible. Among the topics we'll study are sum, product and quotient spaces; duality (kernel, cokernel); tensor product (Hilbert's third problem, differential form); homological algebra (exact sequence, snake lemma); normal forms (Frobenius, Weyr, Smith) and invariant factors. If there are sufficient time and interest, we might explore other topics, such as geometric algebra, control theory (pole placement) and/or tropical linear algebra.

**MATH 1810C. Artificial Intelligence and Euclidean Geometry.**

This course explores the exciting field of automated reasoning systems for complex mathematical problems, inspired by Google DeepMind's AlphaGeometry. We'll delve into the mathematical foundations of such systems, starting with the essentials of Euclidean geometry from Euclid's Elements, including axioms and deductive reasoning. The course structure combines theoretical learning with hands-on experience. We will also focus on the practical application of building a Euclidean geometry reasoning system. Students will work in groups throughout the semester to develop their own system to solve geometry problems. \*\*Admission into this class is by application only. Please contact the Instructors for more information\*\*

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| Fall | MATH1810CS01 | 18097 | MWF | 1:00-1:50(08) | (J. Jung) |
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**MATH 1820A. Introduction to Lie Algebras.**

Lie groups and Lie algebras are important, because they are the symmetries of structures such as quadratic forms, differential systems and smooth manifolds. The prototype of a Lie algebra is the space of 3-vectors together with their cross product, which is closely related to the Lie group of rotations. We will see how this basic example generalizes, mostly in the context of matrices. We'll examine special types of Lie algebras, such as nilpotent, solvable and semi-simple, study root systems and their diagrams, explore some representation theory, and end with the classification of the simple Lie algebras. Prerequisite: MATH 1530.

**MATH 1970. Honors Conference.**

Collateral reading, individual conferences. Section numbers vary by instructor. Please check Banner for the correct section number and CRN to use when registering for this course.

**MATH 2010. Differential Geometry.**

Introduction to differential geometry (differentiable manifolds, differential forms, tensor fields, homogeneous spaces, fiber bundles, connections, and Riemannian geometry), followed by selected topics in the field. Pre-reqs: MATH 2110 and undergraduates require permission from the instructor.

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| Spr | MATH2010 | S01 | 20129 | TTh | 9:00-10:20(05) | (G. Daskalopoulos) |
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**MATH 2050. Algebraic Geometry.**

Complex manifolds and algebraic varieties, sheaves and cohomology, vector bundles, Hodge theory, Kähler manifolds, vanishing theorems, the Kodaira embedding theorem, the Riemann-Roch theorem, and introduction to deformation theory. Pre-reqs: MATH 2510 and MATH 2520 and undergraduates require permission from the instructor.

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| Spr | MATH2050 | S01 | 25937 | MWF | 1:00-1:50(06) | (E. Larson) |
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**MATH 2060. Algebraic Geometry.**

See Algebraic Geometry (MATH 2050) for course description.

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| Fall | MATH2060 | S01 | 17773 | MWF | 1:00-1:50(08) | (E. Larson) |
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**MATH 2110. Introduction to Manifolds.**

Inverse Function Theorem, manifolds and submanifolds, tangent and cotangent bundles, transversality, flows and vector fields, Frobenius Theorem, vector bundles, tensors and differential forms, Sard's Theorem, introduction to Lie groups. Pre-reqs: MATH 1060, MATH 1140 and preferably MATH 1410 and undergraduates require permission from the instructor.

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| Fall | MATH2110 | S01 | 10148 | TTh | 10:30-11:50(13) | (T. Goodwillie) |
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**MATH 2210. Real Function Theory.**

Real numbers, outer measures, measures, Lebesgue measure, integrals of measurable functions, Holder and Minkowski inequalities, modes of convergence,  $L^p$  spaces, product measures, Fubini's Theorem, signed measures, Radon-Nikodym theorem, dual space of  $L^p$  and of  $C$ , Hausdorff measure.

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| Fall | MATH2210 | S01 | 10154 | MWF | 2:00-2:50(01) | (J. Pipher) |
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**MATH 2220. Real Function Theory.**

The basics of Hilbert space theory, including orthogonal projections, the Riesz representation theorem, and compact operators. The basics of Banach space theory, including the open mapping theorem, closed graph theorem, uniform boundedness principle, Hahn-Banach theorem, Riesz representation theorem (pertaining to the dual of  $C_0(X)$ ), weak and weak-star topologies. Various additional topics, possibly including Fourier series, Fourier transform, ergodic theorems, distribution theory, and the spectral theory of linear operators.

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| Spr | MATH2220 | S01 | 20137 | MWF | 1:00-1:50(06) | (J. Pipher) |
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**MATH 2250. Complex Function Theory.**

Introduction to the theory of analytic functions of one complex variable. Content varies somewhat from year to year, but always includes the study of power series, complex line integrals, analytic continuation, conformal mapping, and an introduction to Riemann surfaces.

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| Fall | MATH2250 | S01 | 10149 | TTh | 9:00-10:20(05) | (G. Daskalopoulos) |
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**MATH 2260. Complex Function Theory.**

See Complex Function Theory (MATH 2250) for course description.

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| Spr | MATH2260 | S01 | 20131 | TTh | 2:30-3:50(11) | (J. Jung) |
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**MATH 2370. Partial Differential Equations.**

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

**MATH 2380. Partial Differential Equations.**

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

**MATH 2410. Topology.**

An introduction to algebraic topology. Topics include fundamental group, covering spaces, simplicial and singular homology, CW complexes, and an introduction to cohomology. Pre-reqs: MATH 1410, MATH 1530, and MATH 1010 and/or MATH 1130 and undergraduates require permission from the instructor.

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| Fall | MATH2410 | S01 | 10150 | TTh | 1:00-2:20(06) | (L. Keenan) |
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**MATH 2420. Algebraic Topology.**

This is a continuation of MATH 2410. Topics include cohomology, cup products, Poincaré duality, and other topics chosen by the instructor.

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| Spr | MATH2420 | S01 | 20133 | TTh | 1:00-2:20(08) | (T. Goodwillie) |
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**MATH 2450. Exchange Scholar Program.**

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| Fall | MATH2450 | S01 | 16707 | Arranged |  | 'To Be Arranged' |
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**MATH 2510. Algebra.**

Basic properties of groups, rings, fields, and modules. Topics include: finite groups, representations of groups, rings with minimum condition, Galois theory, local rings, algebraic number theory, classical ideal theory, basic homological algebra, and elementary algebraic geometry. Pre-reqs: MATH 1530 and MATH 1540 and undergraduates require permission from the instructor.

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| Fall | MATH2510 | S01 | 10151 | MWF | 11:00-11:50(16) | (M. Chan) |
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**MATH 2520. Algebra.**

See Algebra (MATH 2510) for course description. Pre-reqs: MATH 2510 and undergraduates require permission from the instructor.

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| Spr | MATH2520 | S01 | 20134 | MWF | 10:00-10:50(03) | (M. Chan) |
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**MATH 2530. Number Theory.**

Introduction to algebraic and analytic number theory. Topics covered during the first semester include number fields, rings of integers, primes and ramification theory, completions, adeles and ideles, and zeta functions. Content of the second semester varies from year to year; possible topics include class field theory, arithmetic geometry, analytic number theory, and arithmetic K-theory. Pre-reqs: MATH 2510 and undergraduates require permission from the instructor.

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| Fall | MATH2530 | S01 | 10152 | MWF | 10:00-10:50(14) | (J. Silverman) |
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**MATH 2540. Number Theory.**

See Number Theory (MATH 2530) for course description.

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| Spr | MATH2540 | S01 | 20135 | MWF | 11:00-11:50(04) | (J. Hoffstein) |
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**MATH 2630. Probability.**

Introduces probability spaces, random variables, expectation values, and conditional expectations. Develops the basic tools of probability theory, such fundamental results as the weak and strong laws of large numbers, and the central limit theorem. Continues with a study of stochastic processes, such as Markov chains, branching processes, martingales, Brownian motion, and stochastic integrals. Students without a previous course in measure theory should take MATH 2210 (or APMA 2110) concurrently.

**MATH 2640. Probability.**

See MATH 2630 for course description.

**MATH 2710A. Probability, Quantum Field Theory, and Geometry.****MATH 2710B. Solitary Waves.****MATH 2710C. Gluing Constructions in Differential Geometry.****MATH 2710D. Lie Groups and Lie Algebras.****MATH 2710E. Arithmetic Groups.****MATH 2710F. Stable Homotopy Theory.**

No description available.

**MATH 2710H. Topics in Complex and p-adic Dynamics.**

No description available.

**MATH 2710I. Topics in Effective Harmonic Analysis.**

Graduate topics course in Harmonic Analysis.

**MATH 2710P. Harmonic Analysis on Polytopes and Cones.**

Graduate Topics course in harmonic analysis.

**MATH 2710R. Problems of the Uncertainty Principle in Harmonic Analysis.**

Graduate Topics course in Harmonic Analysis.

**MATH 2710T. Random Walks, Spanning Trees, and Abelian Sandpiles.**

This is an advanced level discussion seminar for specific topics in probability. We will study random walks on networks, the uniform spanning tree model, and the abelian sandpile model of self-organized criticality, and their connections to one another. Using these connections, we will derive properties of these objects on large graphs. We will also cover related topics such as the random walk loop soup.

**MATH 2720A. Topics in Harmonic Analysis.****MATH 2720B. Multiple Dirichlet Series.****MATH 2720C. Curves on Surfaces and the Classification of Finitely Generated Kleinian Groups.**

This is a course in the study of geometry and topology of hyperbolic 3-manifolds.

**MATH 2720D. Piecewise Isometric Maps.**

This class will cover a variety of topics, all more or less related to dynamical systems that are defined by piecewise isometric maps. Topics may include: polygonal billiards and flat cone surfaces; outer billiards; interval exchange maps; The Gauss map and continued fractions; aperiodic tilings, such as the Penrose tiling; cut and paste theorems about polyhedra; and Ashwin's conjecture about piecewise rotation maps. A fairly large part of the class will be devoted to the explanation of the instructor's proof of the Moser-Neumann conjecture for outer billiards. For this part, the instructor will use his book on the subject. For other parts of the course, a variety of sources will be used.

**MATH 2720E. Advanced Topics in Mathematics.**

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| Fall | MATH2720ES01 | 10153 | TTh | 2:30-3:50(12) | (J. Hoffstein) |
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| Spr | MATH2720ES01 | 20136 | MWF | 10:00-10:50(03) | (S. Treil) |
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**MATH 2720F. Topics in Geometric Analysis.**

No description available.

**MATH 2720G. Introduction to Hodge Structures.**

No description available.

**MATH 2720H. Discrete Groups, Ergodic Theory and Hyperbolic Geometry.**

No description available.

**MATH 2720I. Automorphic Representations for  $GL(2)$ .**

Graduate topics course in automorphic representations for  $GL(2)$ .

**MATH 2720N. Groups Acting on Trees.**

This course will be an introduction to geometric group theory from the viewpoint of groups acting on trees. Some topics that may be covered included Bass-Serre theory, R-trees and the Rips machine and groups acting on quasi-trees.

**MATH 2720O. Equivariant Homotopy Theory.**

This course will serve as an introduction to equivariant homotopy theory, with an emphasis on intuition and with a grounding in concrete computations. We will begin with the homotopy theory of equivariant spaces, seeing what can be said here that mirrors the non-equivariant cases, before introducing stabilization and discussing the kinds of problems stabilization works to solve. Here, we have lots of choices for how we stabilize, and we will spend a little time discussing this and the consequences. Having developed the foundations, the end of the course will focus on student-led presentations on applications of equivariant homotopy theory.

**MATH 2720P. Stability Problems in Non-collisional Kinetic Theory.**

We will cover the local and global well-posedness for solutions to the Vlasov-Poisson problem, consider steady solution and move on to their stability, starting with the stability of vacuum, we will move on to homogeneous equilibrium and the connection to Landau

**MATH 2970. Preliminary Exam Preparation.**

No description available.

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| Fall | MATH2970 | S01 | 16708 | Arranged | 'To Be Arranged' |
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| Spr | MATH2970 | S01 | 25278 | Arranged | 'To Be Arranged' |
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**MATH 2980. Reading and Research.**

Independent research or course of study under the direction of a member of the faculty, which may include research for and preparation of a thesis. Section numbers vary by instructor. Please check Banner for the correct section number and CRN to use when registering for this course.

**MATH 2990. Thesis Preparation.**

For graduate students who have met the residency requirement and are continuing research on a full time basis.

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| Fall | MATH2990 | S01 | 16709 | Arranged | 'To Be Arranged' |
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| Spr | MATH2990 | S01 | 25279 | Arranged | 'To Be Arranged' |
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**MATH XLIST. Courses of Interest to Students Majoring in Mathematics.**