Mathematics

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LECTURERS WITH SECURITY OF EMPLOYMENT

Norman A. Shenk, Ph.D., *Emeritus*
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THE UNDERGRADUATE PROGRAM

The mathematics department offers a wide range of courses in pure and applied mathematics for its majors and for students in other disciplines. The department offers six majors leading to the B.S. degree: mathematics, applied mathematics, mathematics–computer science, joint major in mathematics and economics, mathematics–scientific computation, and probability and statistics, and two leading to the B.A. degree: mathematics-applied science, and mathematics-secondary education. In addition, students can minor in mathematics or mathematics education. The department also has an Honors Program for exceptional students in any of the eight majors. See the sections on major programs and the other areas mentioned above as well as the course descriptions at the end of this section for more specific information about program requirements and the courses offered by the department. You may visit our Web site, http://math.ucsd.edu, for more information, including course Web pages, career advising, and research interests of our faculty.

FIRST-YEAR COURSES

Entering students must take the Mathematics Placement Exam (MPE) prior to orientation unless they have an appropriate score on an AP calculus exam, an appropriate score (600 for Math. 10A; 650 for Math. 20A) on the SAT II Math Level 2 exam, an appropriate score on the International Baccalaureate Higher Level Mathematics Exam, credit by means of a foreign exam (e.g. GCE), or transferable college credit in calculus. The purpose of the MPE is to recommend placement for entering students in Math. 3C, 4C, 10A, or 20A. For more information about the MPE (test dates, test description, sample exams, online practice tests), see the Mathematics Testing and Placement Web site, http://mathtesting.ucsd.edu.

Prerequisites for Math. 3C, 4C, 10A-B-C, 20A-B-C-D-E-F, and 31AH-BH-CH are enforced through TritonLink. Students need to ensure that test scores and transferable college credit are submitted to the Registrar prior to enrollment through WebReg.

Math. 3C is the department's preparatory course for the Math. 10 sequence, providing a review of algebraic skills, facility in graphing, and working with exponential and logarithmic functions.

Math. 4C is the department's preparatory course for the Math. 20 sequence, providing a brief review of college algebra followed by an introduction to trigonometry and a more advanced treatment of graphing and functions.

Math. 10A-B-C is one of three calculus sequences. The students in this sequence have completed a minimum of two years of high school mathematics. This sequence is intended for majors in liberal arts and the social and life sciences. It fulfills the mathematics requirements of Revelle College and the option of the general-education requirements of Muir College. Completion of two quarters fulfills the requirement of Marshall College and the option of Warren College and Eleanor Roosevelt College.

The second first-year calculus sequence, Math. 20A-B-C, is taken mainly by students who have completed four years of high school mathematics or have taken a college level precalculus course such as Math. 4C. This sequence fulfills all college level requirements met by Math. 10A-B-C and is required of many majors, including chemistry and biochemistry, bioengineering, cognitive science, economics, mathematics, molecular biology, psychology, MAE, CSE, ECE, and physics. Students with adequate backgrounds in mathematics are strongly encouraged to take Math. 20 since it provides the foundation for Math. 20D-E-F which is required for some science and engineering majors. **Note:** As of summer 2003, Math. 21C and 21D have been renumbered to Math. 20C and 20D.

Certain transfers between the Math. 10 and Math. 20 sequences are possible, but such transfers should be carefully discussed with an advisor. Able students who begin the Math. 10 sequence and who wish to transfer to the Math. 20 sequence, may follow one of three paths:

1. Follow Math. 10A with Math. 20A, with two units of credit given for Math. 20A. This option is not available if the student has credit for Math. 10B or Math. 10C.
2. Follow Math. 10B with Math. 20B, receiving two units of credit for Math. 20B.
3. Follow Math. 10C with Math. 20B, receiving two units of credit for Math. 20B and two units of credit for Math. 20C.

Credit will not be given for courses taken simultaneously from the Math. 10 and the Math. 20 sequence.

The department also offers a three-quarter Honors Calculus sequence in Multivariable and Vector Calculus and Linear Algebra. This sequence, Math. 31AH-BH-CH, is designed for well-prepared students who have both a strong aptitude and a deep interest in mathematics and who wish to undertake a challenging series of courses. The sequence has a prerequisite of a score of 5 on the AP Calculus BC exam. These demanding, proof-based courses cover the material in Math. 20F, 20C, and 20E respectively—and entering students with a 5 on the Calculus BC exam should consider starting in the Honors sequence if their major (or minor) program requires them to take, at least, Math. 20A-B-C and 20F. Math. majors who complete the entire three-quarter honors sequence will have also satisfied the requirement of Math. 109 for their major program. They would be able to replace Math. 109 with any four-unit upper-division mathematics elective course.

MAJOR PROGRAMS

The department offers six different majors leading to the B.S. degree: (1) mathematics, (2) applied mathematics, (3) mathematics-computer science, (4) joint major in mathematics and economics, (5) mathematics-scientific computation, and (6) probability and statistics, and two leading to the B.A. degree: (1) mathematics-applied science, and (2) mathematics-secondary education. The specific emphases and course requirements for these majors are described in the following sections. All majors must obtain a minimum 2.0 grade-point average in the upper-division courses used to satisfy the major requirements. Further, the student must receive a grade of C– or better in any course to be counted toward fulfillment of the major requirements. Any mathematics course numbered 100–194 may be used as an upper-division elective. (**Note:** 195, 196, 197, 198, 199, and 199H cannot be used towards any mathematics major.) All courses used to fulfill the major must be taken for a letter grade. No more than three upper-division courses taken externally from UCSD can be counted towards any major. Special exceptions may be considered via petition.

It is strongly recommended that all mathematics majors review their programs at least annually with a departmental advisor, and that they consult with the Advising Office in AP&M 6016 before making any changes to their programs. Current course offering information for the entire academic year is maintained on the department's Web page at http://www.math.ucsd.edu. Special announcements are also e-mailed to all majors.

Students who plan to go on to complete a Ph.D. in mathematics should be advised that only the best and most motivated students are admitted. Many graduate schools expect that students will have completed a full sequence of abstract algebra (Math. 100A-B-C) as well as a full sequence of analysis (Math. 140A-B-C). The advanced Graduate Record Exam (GRE) often has questions that pertain to material covered in the last quarter of analysis or algebra. In addition, it is advisable that students consider Summer Research Experiences for Undergraduates. This is a program funded by the National Science Foundation to introduce students to math research while they are still undergraduates. In their senior year or earlier, students should consider taking some graduate courses so that they are exposed to material taught at a higher level. In their junior year, students should begin to think of obtaining letters of recommendation from professors who are familiar with their abilities.

Note: Math. 20D, E, and F do not need to be taken in order. Math majors are strongly advised to take 20F as early as possible after successfully completing 20C.

EDUCATION ABROAD

Students may be able to participate in the UC Education Abroad Program (EAP) and UC San Diego's Opportunities Abroad Program (OAP) while still making progress towards the major. Students interested in this option should contact the Programs Abroad Office in the International Center and discuss their plans with the mathematics advising officer before going abroad.

The department must approve courses taken abroad. Information on EAP/OAP can be found in the "Education Abroad Program" section of the *UC San Diego General Catalog* and the Web site http://pao.ucsd.edu.

MAJOR IN MATHEMATICS

The upper-division curriculum provides programs for mathematics majors as well as courses for students who will use mathematics as a tool in the biological, physical and behavioral sciences, and the humanities.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D

Upper-Division

2. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
3. One of the following sequences:
   a. Foundations of Analysis: Math. 140A-B
   b. Advanced Calculus: Math. 142A-B and Math. 120A (Math. 140A-B-C recommended for graduate school)
4. One of the following sequences:
   a. Modern Algebra: Math. 100A-B
   b. Modern Applied Algebra: Math. 103A-B and Math. 102 (Math. 100A-B-C recommended for graduate school)
5. Upper-division electives to complete thirteen four-unit courses, chosen from any mathematics course numbered between 100 and 194 (including those taken from the requirements listed above.)

As with all departmental requirements, more advanced courses on the same material may be substituted with written approval from the departmental advisor.

To be prepared for a strong major curriculum, students should complete the last three quarters of the 20 sequence and Math. 109 before the end of their sophomore year. Either Math. 140A-B or 100A-B should be taken during the junior year.

MAJOR IN APPLIED MATHEMATICS

A major in applied mathematics is also offered. The program is intended for students planning to work on the interface between mathematics and other fields.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D
2. Programming (one of the following):
   a. SE 8A-AL-B (Intro to Computer Sci: Java)
   b. CSE 11 (Intro to Computer Sci: Java, Accelerated Pace)
   c. MAE 9 (C/C++ Programming)

Upper-Division

3. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
4. Linear Algebra: Math. 102 or Math. 170A
5. Advanced Calculus: Math. 140A-B or Math. 142A-B
6. One of the following sequences:
   a. Math. 180A-B-C-181A
   b. Math. 180A-181A and any two from Math. 181B-C-E
   c. (Math. 183 or Math. 180A-181A) and any three from Math. 170A-B-C-175-179
7. One additional sequence which may be chosen from the list (#6) above or the following list: Math. 110A-120A-130A, 110A-B, 120A-B, 152-184A, 154-184A, 155A-B, 171A-B, 193A-B.
8. Upper-division electives to complete at least thirteen four-unit courses, chosen from any mathematics course numbered between 100 and 194 (including those taken from the requirements listed above) except
   a. Up to twelve units may be taken from outside the department in an approved applied mathematical area. A petition specifying the courses to be used must be approved by an applied mathematics advisor. No such units may also be used for a minor or program of concentration.
   b. MAE 107, Econ. 120A-B-C, cannot be counted toward the thirteen required courses.

To be prepared for a strong major curriculum, students should complete the last three quarters of

the 20 sequence and Math. 109 before the end of their sophomore year.

MAJOR IN MATHEMATICS–SCIENTIFIC COMPUTATION

This major is designed for students with a substantial interest in scientific computation. The program is a specialized applied mathematics program with a concentration in computer solutions of scientific problems.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D
2. Computer Programming: MAE 9 and [CSE 8A-AL-B or CSE 11]
3. Basic Computation: Math. 15A (or CSE 20) and Math. 15B (or CSE 21) and CSE 12

Upper-Division

4. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
5. Linear Algebra: Math. 102
6. Probability and Statistics: Math. 183 or 180A-181A (Note: No credit for Math. 183 if Math. 180A or 181A taken prior or concurrently.)
7. Analysis: Math. 140A-B or 142A-B
8. Numerical Analysis: Math. 170A-B-C or Math. 170A-B/Math. 175
9. Optimization: Math. 171A-B
10. Scientific Computing: Math. 179
11. Additional elective upper-division courses to total 15 chosen from the following: Math. 107A-B, 110A-B, 120A-B, 130A-B, 131, 152, 155A-B, 170C, or 175.

    At least 15 upper-division mathematics courses are required for the major, except

    a. Up to 3 upper-division courses may be taken outside the department in an approved scientific computation area in the sciences or engineering. A petition specifying the courses to be used must be approved by a mathematics-scientific computation advisor.
    b. MAE 107, Econ. 120A-B-C, Math. 195, 196, 197, 199, and 199H cannot be counted toward the 13 four-unit upper-division courses.

MAJOR IN MATHEMATICS–PROBABILITY AND STATISTICS

Effective Winter 2007

This major is designed for students with a substantial interest in probability theory and statistics. It is useful preparation for many fields of employment as well as graduate school.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D
2. Programming (one of the following):
   1. CSE 8A-AL-B (Java)
   2. CSE 11 (Java: Accelerated Pace)
   3. MAE 9 (C/C++)

Upper-Division

3. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
4. Linear Algebra: Math. 102 or Math. 170A
5. Analysis/Advanced Calculus: Math. 140A-B or Math. 142A-B
6. Numerical Methods: Math. 174 or Math. 170A-B
7. Probability: Math. 180A-B-C
8. Mathematical Statistics: Math. 181A-B
9. One of the following: Math. 181C, 181E, 193A, 193B, 194
10. Computational Statistics: Math. 185
11. Upper-division electives to complete 15 upper-division courses from the following list: Math. 100A-B-C, 103A-B, 110A-B, 120A-B, 130A, 131, 140C, 152, 155A-B, 170A-B-C, 171A-B, 175, 176, 179, 181C, 181E, 184A, 187, 188, 193A-B, 194.

    At least 15 four-unit upper-division mathematics courses are required, except

    a. Two upper-division electives may be outside the department in an approved applied mathematical area. A petition approved by a math advisor is required.
    b. MAE 107, Econ. 120A-B-C, Math. 195-199 cannot be counted toward the upper-division requirements.

To be prepared for a strong major curriculum, students should complete the last three quarters of the 20 sequence and Math. 109 before the end of their sophomore year.

MAJOR IN MATHEMATICS–APPLIED SCIENCE

This major is designed for students with a substantial interest in mathematics and its applications to a particular field such as physics, biology, chemistry, biochemistry, cognitive science, computer science, economics, management science, or engineering.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D
2. Programming (one of the following is required):
   a. CSE 8A-AL-B (Intro to Computer Sci: Java)
   b. CSE 11 (Intro to Computer Sci: Java, Accelerated Pace)
   c. MAE 9 (C/C++ Programming)

Upper-Division Mathematics Requirements

3. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
4. Linear Algebra: Math. 102 or Math. 170A
5. Analysis: Math. 140A-B or 142A-B
6. Any two-quarter, upper-division math sequence
7. Upper-division electives to complete at least seven four-unit courses, chosen from any mathematics course numbered between 100 and 194 (including those taken from the requirements listed above.)

Upper-Division Applied Science Requirements

8. Seven upper-division courses selected from one or two other departments (these cannot be from mathematics). At least three of these seven upper-division courses must require calculus as a prerequisite.

Students must submit an individual plan for approval in advance by a mathematics department advisor, and all subsequent changes to the plan must be approved by a mathematics department advisor.

MAJOR IN MATHEMATICS–COMPUTER SCIENCE

Graduates of this program will be mathematically oriented computer scientists who have specialized in the mathematical aspects and foundations of computer science or in the computer applications of mathematics.

As of fall 2000, a mathematics–computer science major is not allowed to also minor in computer science in the Computer Science and Engineering department.

The detailed curriculum is given in the list below:

MATHEMATICS–COMPUTER SCIENCE PRE-MAJOR

In October 2001, the Academic Senate approved a minimum GPA requirement of 2.5 in the lower-division mathematics courses required for the mathematics–computer science major. The 2.5 minimum GPA in the lower-division math courses

reflects minimal preparation for the upper-division courses required for the major.

Therefore, students entering UCSD as first- year students for the fall 2002 quarter and later and students entering as transfer students for the fall 2003 quarter and later will be held to this requirement. Applications from students entering UCSD on or after the effective dates above will be held until all lower-division math courses for the major are completed and the minimum GPA in those courses of 2.5 can be verified. Students meeting the 2.5 minimum GPA requirement will be accepted into the mathematics–computer science major.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D
2. Intro to Computer Science—CSE 8A-AL-B Introduction to Computer Science: Java, or CSE 11 Introduction to Computer Science: Java (Accelerated)
3. Basic Data Structures and Object-oriented Programming: CSE 12
4. Computer Organization and Systems Programming: CSE 30 (Note: CSE 30 requires CSE 20 or Math. 15A as a prerequisite.)

Upper-Division:

5. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
6. Modern Applied Algebra: Math. 103A-B or Modern Algebra: Math. 100A-B
7. Theory of Computability: Math. 166 (or CSE 105)
8. Intro to Probability: Math. 180A or 183
9. Combinatorics: Math. 184A
10. Computer Implementations of Data Structures: Math. 176 (or CSE 100)
11. Design & Analysis of Algorithms: Math. 188 (or CSE 101)
12. Eight units from: Math. 170A-B-C, 174, 175, 179 (Note duplication of credit between Math. 174 and 170A-B-C)
13. Eight units from: Math. 107A-B, 152, 154, 155A-B, 168A-B, 187, CSE 120-121, 130, 131A-B, 140-140L, 141-141L, 167
14. Eight additional units from: any course in list #12 or #13 above or Math. 102, 110A-B, 111A-B, 120A-B, 130A-B, 131, 140A-B, 142A-B, 150A-B, 181A-B-C

JOINT MAJOR IN MATHEMATICS AND ECONOMICS

Majors in mathematics and the natural sciences often feel the need for a more formal introduction to issues involving business applications of science and mathematics. Extending their studies into economics provides this application and can provide a bridge to successful careers or advanced study. Majors in economics generally recognize the importance of mathematics to their discipline. Undergraduate students who plan to pursue doctoral study in economics or business need the more advanced mathematics training prescribed in this major.

This major is considered to be excellent preparation for Ph.D. study in economics and business administration, as well as for graduate studies for professional management degrees, including the MBA. The major provides a formal framework making it easier to combine study in the two fields.

Course requirements of the Joint Major in Mathematics and Economics consist principally of the required courses of the pure mathematics major and the economics/management science major.

Required Courses

Lower-Division

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-F
   b. Honors Calculus: Math. 31AH-BH, Math. 20D
2. Intro. to Economics: Econ. 1 and 3

Upper-Division

Fifteen upper-division courses in mathematics and economics, with a minimum of seven courses in each department, chosen from the courses listed below (prerequisites are strictly enforced):

3. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109.)
4. One of the following: Applied Linear Algebra: Math. 102 Numerical Linear Algebra: Math. 170A Modern Algebra: Math. 100A-B
5. One of the following: Foundations of Analysis: Math. 140A Advanced Calculus: Math. 142A
6. One of the following: Ordinary Differential Equations: Math. 130A, Foundations of Analysis: Math. 140B Advanced Calculus: Math. 142B
7. Microeconomics: Econ. 100A-B-C
8. Econometrics: Econ. 120A-B-C or Math. 180A and Econ. 120B-C or Probability: Math. 180A, 181A and Econ. 120C
9. One of the following:
   a. Macroeconomics: Econ. 110A-B
   b. Mathematical Programming: Numerical Optimization: Math. 171A-B

   or two courses from the following:
   c. Decisions Under Uncertainty: Econ. 171
   d. Introduction to Operations Research: Econ. 172A-B, (Note: 172A is a prerequisite for 172B-C.)

Other courses which are strongly recommended are Math. 130B, 131, 181B, 193A-B and 194 and Econ. 109, 113, 175, and 178.

MAJOR IN MATHEMATICS–SECONDARY EDUCATION

This major offers excellent preparation for teaching mathematics in secondary schools. Students interested in earning a California teaching credential from UCSD should contact the Education Studies Program (EDS) for information regarding prerequisites and requirements. It is recommended you contact EDS as early as possible.

Lower-Division Requirements

1. One of the following sequences:
   a. Calculus: Math. 20A-B-C-D-E-F
   b. Honors Calculus: Math. 31AH-BH-CH, Math. 20D

   Recommended:
2. One of the following: Introduction to Computer Science: Java: CSE 8A-AL-B, C/C++ Programming: MAE 9

Upper-Division Requirements

3. Mathematical Reasoning: Math. 109 (**Note:** Students completing Math. 31CH may substitute a four-unit upper-division mathematics elective for Math. 109)
4. Number Theory: Math. 104A
5. History of Mathematics: Math. 163
6. Practicum in Learning: EDS 129A-B-C (can use EDS 136 and EDS 138 instead of EDS 129A)
7. One of the following: Computer Algebra: Math. 107A, Computer Graphics: Math. 155A, Numerical Linear Algebra: Math. 170A, Intro. to Cryptography: Math. 187
8. One of the following: Intro. to Probability: Math. 180A, Statistical Methods: Math. 183
9. One of the following: Differential Geometry: Math. 150A, Topics in Geometry: Math 151, Geometry for Secondary Teachers: Math. 153, Intro. to Topology: Math. 190
10. One of the Following: Modern Algebra: Math. 100A, Applied Linear Algebra: Math. 102, Modern Applied Algebra: Math. 103A
11. One of the following: Foundations of Analysis: Math. 140A, Advanced Calculus: Math. 142A
12. Upper-division courses must total thirteen courses. Upper-division courses must include at least one two-quarter sequence from the following list:
    100A-B; 103A-B, 103A-102; 104A-B; 110A-B; 110A-120A; 110A-130A; 110A-131; 120A-B; 140A-B; 142A-B; 150A-B; 152-184A; 154-184A; 155A-B; 160A-B; 170A-B; 170A-175; 170A-171A; 170A-179; 171A-B; 180A-B; 180A-181A; 193A-B.

MINOR IN MATHEMATICS

The minor in mathematics consists of seven or more courses. At least four of these courses must be upper-division courses taken from the UCSD Department of Mathematics. Acceptable lower-

division courses are Math. 20D, 20E (or 31CH), and 20F (or 31AH).

Math. 195, 196, 197, 198, 199, and 199H are not acceptable courses for the mathematics minor. A grade of C– or better (or P if the Pass/Not Pass option is used) is required for all courses used to satisfy the requirements for a minor. There is no restriction on the number of classes taken with the P/NP option. Upper-division courses cannot overlap between major and minor programs.

MINOR IN MATHEMATIC EDUCATION

The education studies mathematics education minor is intended for students interested in understanding how people learn mathematics, including: students considering K-12 teaching as a career; students interested in teaching at the college level; and students who are interested in becoming better, more reflective learners. All majors are welcome, but the Calculus 10 or 20 sequence is a prerequisite for two of the upper-division courses required for the minor. For more information contact Education Studies: http://eds.ucsd.edu/undergraduate/minors.shtml.

MATHEMATICS HONORS PROGRAM

The Department of Mathematics offers an honors program for those students who have demonstrated excellence in the major. Successful completion of the honors program entitles the student to graduate with departmental honors (see Department Honors in the Academic Regulations section).

For Mathematics, Applied Mathematics, Mathematics–Scientific Computation, Mathematics–Applied Science, Mathematics–Secondary Education, Mathematics–Computer Science, and Probability and Statistics Majors:

Requirements for admission to the program are

1. Junior standing
2. An overall GPA of 3.0 or higher
3. A GPA in the major of 3.5 or higher
4. Completion of Math. 109 (Mathematical Reasoning) or Math. 31CH (Honors Vector Calculus) and at least one of Math. 100A, 103A, 140A, or 142A. (Completion of additional major courses is strongly recommended.)

Applications to the program should be made the spring quarter before the student is at senior standing.

Completion of the honors program requires the following:

1. At least one quarter of the student colloquium, Math. 196 (Note: Math. 196 is only offered in the fall quarter.)
2. The minimum 3.5 GPA in the major must be maintained
3. An Honors Thesis. The research and writing of the thesis will be conducted over at least two quarters of the junior/senior years under the supervision of a faculty advisor. This research will be credited as eight to twelve units of Math. 199H. The completed thesis must be approved by the department's Honors Committee, and presented orally at the Undergraduate Research Conference or another appropriate occasion.

The department's Honors Committee will determine the level of honors to be awarded, based on the student's GPA in the major and the quality of the honors work. Applications for the mathematics department's Honors Program can be obtained at the mathematics department Undergraduate Affairs Office (AP&M 7018) or the Mathematics Advising Office (AP&M 6016). Completed applications can be returned to the Mathematics Advising Office.

For Joint Mathematics and Economics Majors:

To graduate with honors requires the following:

1. At least one quarter of the Student Colloquium, Math. 196 (Note: Math. 196 is only offered in the fall quarter.)
2. At least one Economics honors course: Econ. 100AH, 100BH, 110AH, 110BH, 120AH, 120BH, 120CH. Note: enrollment in these honors classes is by special permission; check with the undergraduate advisors in the Economics Student Services Office (SH 245).
3. An Honors Thesis. The research and writing of the thesis will be conducted over two quarters of the senior year under the supervision of a faculty advisor. The completed thesis must be approved by the Joint Mathematics and Economics Honors Committee, which comprises the Mathematics Honors Committee and the Economics Honors Committee, and presented orally at the Undergraduate Research Conference or another appropriate occasion.
   a. If the student is a declared major in the mathematics department (MA33), this thesis will be credited as eight units of Math. 199H. Enrollment in Math. 199H is by special permission; check with the advisors in the mathematics department Undergraduate Affairs Office (AP&M 7018) or the Mathematics Advising Office (AP&M 6016).
   b. If the student is a declared major in the economics department (EN28), the student must enroll in Econ. 191A-B. Enrollment in Econ. 191 is by special permission; check with the undergraduate advisors in the Economics Student Services Office (SH 245).
4. A minimum GPA of 3.0 overall, 3.5 in the upper-division courses required for the major and a 3.5 in the following four classes: Math. 196, Economics Honors class and either Econ. 191A-B or two quarters of Math. 199H.

The Joint Mathematics and Economics Honors Committee will determine the level of honors to be awarded, based on the student's GPA in the major and the quality of the honors work.

DUPLICATION OF CREDIT

Information on duplication of credit (both full and partial) can be found in the course descriptions. It is the student's responsibility to be aware of the credit restrictions listed.

Faculty Advisors

Advisors change yearly. Contact the undergraduate office at (858) 534-3590 for current information.

THE GRADUATE PROGRAM

The Department of Mathematics offers graduate programs leading to the M.A. (pure or applied mathematics), M.S. (statistics), and Ph.D. degrees.

The application deadline for fall admission is January 7 for Ph.D. candidates, and February 7 for M.A./M.S. candidates. Candidates should have a bachelor's or master's degree in mathematics or a related field from an accredited institution of higher education or the equivalent. A minimum scholastic average of B or better is required for course work completed in upper-division or prior graduate study. In addition, the department requires all applicants to submit scores no older than twelve months from both the GRE General Test and Advanced Subject Test in Mathematics. Completed files are judged on the candidate's mathematical background, qualifications, and goals.

Departmental support is typically in the form of teaching assistantships, research assistantships, and fellowships. These are currently only awarded to students in the Ph.D. program.

GENERAL REQUIREMENTS

All student course programs must be approved by a faculty advisor prior to registering for classes each quarter, as well as any changes throughout the quarter.

Full-time students are required to register for a minimum of twelve (12) units every quarter, eight (8) of which must be graduate-level mathematics courses taken for a letter grade only. The remaining four (4) units can be approved upper-division or graduate-level courses in mathematics-related subjects (Math. 500 may not be used to satisfy any part of this requirement). After advancing to candidacy, Ph.D. candidates may take all course work on a Satisfactory/Unsatisfactory basis. Typically, students should not enroll in Math. 299 until they have satisfactorily passed both qualifying examinations (see "Ph.D. in Mathematics") or obtained approval of their faculty advisor.

MASTER OF ARTS IN PURE MATHEMATICS

[Offered only under the Comprehensive Examination Plan.] The degree may be terminal or obtained on the way to the Ph.D. A total of forty-eight units of credit is required. Twenty-four of these units must be graduate-level mathematics courses approved in consultation with a faculty advisor.

In the selection of course work to fulfill the remaining twenty-four units, the following restrictions must be followed:

1. No more than eight units of upper-division mathematics courses.
2. No more than twelve units of graduate courses in a related field outside the department (approved by the Department of Mathematics).
3. No more than four units of Math. 295 (Special Topics) or Math. 500 (Apprentice Teaching).
4. No units of Math. 299 (Reading and Research) may be used in satisfying the requirements for the master's degree.

Comprehensive Examinations

Seven written departmental examinations are offered in three areas (refer to "Ph.D. In Mathematics," Areas 1, 2, and 3, for list of exams). A student must complete two examinations, one from Area 1 and one from Area 2, both with an M.A. pass or better.

Foreign Language Requirement

A reading knowledge of one foreign language (French, German, or Russian) is required. In exceptional cases other languages may be substituted. Testing is administered by faculty in the department who select published mathematical material in one of these languages for a student to translate.

Time Limits

Full-time students are permitted seven quarters in which to complete all degree requirements. While there are no written time limits for part-time students, the department has the right to intervene and set individual deadlines if it becomes necessary.

MASTER OF ARTS IN APPLIED MATHEMATICS

[Offered only under the Comprehensive Examination Plan] The degree may be terminal or obtained on the way to the Ph.D. Out of the total forty-eight units of required credit, two applied mathematics sequences comprising twenty-four units must be chosen from the following list (not every course is offered each year):

202A-B-C. (Applied Algebra)
210A-B-C. (Mathematical Methods in Physics and Engineering)
261A-B-C. (Probabilistic Combinatorics and Algorithms)
264A-B-C. (Combinatorics)
270A-B-C. (Numerical Mathematics)
271A-B-C. (Numerical Optimization)
272A-B-C. (Numerical Partial Differential Equations)
273A-B-C. (Advanced Techniques in Computational Math)

In certain cases, a petition may be approved to substitute one of these requirements from the following list of sequences:

220A-B-C. (Complex Analysis)
231A-B-C. (Partial Differential Equations)
240A-B-C. (Real Analysis)
280A-B-C. (Probability Theory)
281A-B-C. (Mathematical Statistics)
282A-B. (Applied Statistics)

In choosing course work to fulfill the remaining twenty-four units, the following restrictions must be followed:

1. At least eight units must be approved graduate courses in mathematics or other departments [a one-year sequence in a related area outside the department such as computer science, engineering, physics, or economics is strongly recommended];
2. A maximum of eight units can be approved upper-division courses in mathematics; and
3. A maximum of eight units can be approved upper-division courses in other departments.
4. A maximum of four units of Math. 500 (Apprentice Teaching).
5. NO UNITS of Math. 295 (Special Topics) or Math. 299 (Reading and Research) may be used.

Students are strongly encouraged to consult with a faculty advisor in their first quarter to prepare their course of study.

Comprehensive Examinations

Two written comprehensive examinations must be passed at the master's level in any of the required applied mathematics sequences listed above. The instructors of each course should be contacted for exam details.

Foreign Language Requirement

There is no foreign language requirement for the M.A. in applied mathematics.

Time Limits

Full-time M.A. students are permitted seven quarters in which to complete all requirements. While there are no written time limits for part-time students, the department has the right to intervene and set individual deadlines if it becomes necessary.

MASTER OF SCIENCE IN STATISTICS

[Offered only under the Comprehensive Examination Plan.] The M.S. in statistics is designed to provide recipients with a strong mathematical background and experience in statistical computing with various applications. Out of the forty-eight units of credit needed, required core courses comprise twenty-eight units, including

- Math. 281A-B-C. (Mathematical Statistics)
- Math. 282A-B. (Applied Statistics)

and any two topics comprising eight units chosen freely from Math. 287A-B-C and 289A-B (see course descriptions for topics).

The following guidelines should be followed when selecting courses to complete the remaining twenty units:

1. For a theoretical emphasis, Math. 280A-B-C (Probability Theory) is required.
2. For an applied orientation, Math. 270A-B-C (Numerical Mathematics) is recommended.
3. A maximum of eight units of approved upper-division applied mathematics courses (see faculty advisor) and Math. 500 (Apprentice Teaching).

Upon the approval of the faculty advisor, the rule above, limiting graduate units from other departments to eight may be relaxed in making up these twenty non-core units.

Comprehensive Examinations

Two written comprehensive examinations must be passed at the master's level in related course work (approved by a faculty advisor). Instructors of the relevant courses should be consulted for exam dates as they vary on a yearly basis.

Foreign Language Requirement

There is no foreign language requirement for the M.S. in statistics.

Time Limits

Full-time M.S. students are permitted seven quarters in which to complete all requirements. While there are no written time limits for part-time students, the department has the right to intervene and set individual deadlines if it becomes necessary.

PH.D. IN MATHEMATICS

Written Qualifying Examinations

The department offers written qualifying examinations in seven subjects. These are grouped into three areas as follows:

Area #1

Complex Analysis (Math. 220A-B-C) Real Analysis (Math. 240A-B-C)

Area #2

Algebra (Math. 200A-B-C) Applied Algebra (Math. 202A-B-C) Topology (Math. 290A-B-C)

Area #3

Numerical Analysis (Math. 270A-B-C) Statistics (Math. 281A-B-C)

1. Three qualifying exams must be passed. At least one must be passed at the Ph.D. level, and a second must be passed at either the Ph.D. or Provisional Ph.D. Level The third exam must be passed at least at the master's level.
2. Of the three qualifying exams, there must be at least one from each of Areas #1 and #2. Algebra and Applied Algebra do not count as distinct exams in Area #2.
3. Students must pass a least two exams from distinct areas with a minimum grade of Provisional Ph.D. (For example, a Ph.D. pass in Real Analysis, Provisional Ph.D. Pass in Complex Analysis, M.A. pass in Algebra would NOT satisfy this requirement, but a Ph.D. Pass in Real Analysis, M.A. pass in Complex Analysis, Provisional Ph.D. Pass in Algebra would, as would a Ph.D. Pass in Numerical Analysis, Provisional Ph.D. Pass in Applied Algebra, and M.A. pass in Real Analysis.)

4. All exams must be passed by the September exam session prior to the beginning of the third year of graduate studies. (Thus, there would be no limit on the number of attempts, encouraging new students to take exams when they arrive, without penalty.)

Department policy stipulates that at least one of the exams must be completed with a Provisional Ph.D. Pass or better by September following the end of the first year. Anyone unable to comply with this schedule will lose their funding as a Ph.D. student. They will be terminated from the doctoral program and transferred to one of our master's programs.

Any master's student can submit for consideration a written request to transfer into the Ph.D. Program when the qualifying exam requirements for the Ph.D. Program have been met and a dissertation advisor is found. Approval by the Qualifying Exam and Appeals Committee (QEAC) is not automatic, however.

Exams are typically offered twice a year, one scheduled in the spring quarter and again in early September (prior to the start of fall quarter). Copies of past exams are made available for purchase in the Graduate Office.

In choosing a program with an eye to future employment, students should seek the assistance of a faculty advisor and take a broad selection of courses including applied mathematics, such as those in Area #3.

Foreign Language Requirement

A reading knowledge of one foreign language (French, German, or Russian) is required prior to advancing to candidacy. In exceptional cases other languages may be substituted. Testing is administered within the department by faculty who select published mathematical material in one of these languages for a student to translate.

Advancement to Candidacy

It is expected that by the end of the third year (nine quarters), students should have a field of research chosen and a faculty member willing to direct and guide them. A student will advance to candidacy after successfully passing the oral qualifying examination, which deals primarily with the area of research proposed but may include the project itself. This examination is conducted by the student's appointed doctoral committee. Based on their recommendation, a student advances to candidacy and is awarded the C.Phil. degree.

Dissertation and Final Defense

Submission of a written dissertation and a final examination in which the thesis is publicly defended are the last steps before the Ph.D. degree is awarded. When the dissertation is substantially completed, copies must be provided to all committee members at least four weeks in advance of the proposed defense date. Two weeks before the scheduled final defense, a copy of the dissertation must be made available in the department for public inspection.

Time Limits

The normative time for the Ph.D. In mathematics is five years. Students must have a dissertation advisor by the end of nine quarters. Students must be advanced to candidacy by the end of eleven quarters. Total university support cannot exceed six years. Total registered time at UCSD cannot exceed seven years.

A student making normal progress must meet the time limits described below. Ph.D. students who fail to meet these time limits may lose their TA funding.

1. Pass Qualifying Exams requirement by the fall quarter of the beginning of the third year.
2. Find Thesis advisor by the end of nine quarters.
3. Advance to Candidacy by the end of eleven quarters.
4. Final Defense by the end of the fifth year.

PH.D. IN MATHEMATICS WITH SPECIALIZATION IN COMPUTATIONAL SCIENCE

The Ph.D. in mathematics, with a Specialization in Computational Science is designed to allow a student to obtain standard basic training in his or her chosen field of science, mathematics, or engineering with training in computational science integrated into those graduate studies. The Specialization in Computational Science recognizes the nation's growing and continuing need for broadly trained advanced computational scientists in academic, industry, and government laboratories. Its graduates will be well-positioned to compete effectively for the best jobs in these areas.

Computational science refers to the use of computer simulation and visualization for basic scientific research, product development, and forecasting. It is an interdisciplinary field that combines mathematics (mathematical modeling, numerical analysis) and computer science (architecture, programming, networks, graphics) with one of the scientific or engineering disciplines.

The specialization draws upon the expertise of faculty from bioengineering, biological sciences, chemistry and biochemistry, computers and engineering, electrical and computer engineering, mathematics, mechanical and aerospace engineering, physics, Scripps Institution of Oceanography, structural engineering as well as research staff from the San Diego Supercomputer Center.

Admission

Prospective students must apply to the Ph.D. program of a participating home department, be admitted to that department and then be admitted to the specialization. The five participating academic departments that have a Specialization in Computational Science are chemistry and biochemistry, computer science and engineering, mathematics, mechanical and aerospace engineering, and physics. Requirements consist of those of the admitting home department (one of the five participating departments) as well as the proficiency, qualifying. and elective course requirements as outlined below. Requirements and policies relating to the home department can be found in the *UC San Diego General Catalog* under that department's name. In the case of the mathematics department, the admission requirements for the mathematics doctoral program are those outlined above.

Specialization in Computational Science Policies

1. The specialization requires that students complete all home department requirements for the Ph.D. along with satisfying the CSME proficiency, qualifying, and elective requirements. In the case of the mathematics department, the requirements and timelines for the normal mathematics Ph.D. program are as described above.
2. CSME Proficiency (see below) must be satisfied by the end of the first year.
3. The CSME qualifying exams must be passed by the end of the second year or, on petition, by end of the third year.
4. The CSME qualifying exams can be attempted repeatedly but no more than once per quarter per subject.
5. The regular qualifying exams in the home department and the CSME qualifying exams must all be passed before the student is permitted to take the candidacy (Senate) exam.
6. Two CSME electives outside the home department must be taken.
7. The two CSME electives can be taken at any time before defending the thesis.
8. One of the CSME electives may be taken Pass/Fail; the other must be taken for a letter grade.
9. No CSME field examination requirements will be imposed beyond those of the admitting home department.
10. No CSME foreign language requirements will be imposed beyond those of the admitting home department.

Proficiency Requirements: All Ph.D. students participating in the CSME doctoral program must demonstrate advanced undergraduate level proficiency in numerical analysis and in computer algorithms and data structures. Proficiency may be demonstrated by taking UCSD's courses in both subjects while enrolled in the graduate program (four units per course):

1. Numerical Methods (Math. 174/274 or MAE 290A)
2. Data Structures and Algorithms (CSE 100/101)

Alternatively, proficiency in the material contained in these courses may be satisfied by having previously taken these or equivalent courses at other institutions, or through other evidence of sufficient knowledge of this material. Demonstrating proficiency without taking these courses at UCSD is subject to approval by the CSME Executive Committee on an individual basis.

Qualifying Requirements: In addition to the home department qualifying exam requirements, Ph.D. students participating in the CSME doctoral program must pass the final exams in all three qualifying exam courses listed below. The three qualifying

exam courses have been selected to provide a general broad set of tools in computational science. It is expected that most students will register for and take these courses (four units per course), but the CSME Qualifying Exam Committee may allow an exceptionally well-prepared student to take the final exams without taking the courses. Students must pass the qualifying examinations by the end of the second year or, on petition, by the end of the third year.

1. Math. 275 or MAE 290B (Numerical PDEs)
2. Phys. 244 or CSE 260 (Parallel Computing)
3. Course to be selected from List A

LIST A: CSME Qualifying Exam Courses

Courses taken to satisfy the qualifying requirements cannot count toward the elective requirements.

1. Phys. 243 (Stochastic Methods)
2. Math. 270A, B, or C (Numerical Analysis; not permitted for math. students, who typically take Math. 270A-B-C as a normal mathematics qualifying course.)
3. Math. 272A, B, or C (Advanced Numerical PDEs)
4. MAE 223 (Computational Fluid Dynamics)
5. MAE 232A or B (Computational Solid Mechanics)
6. MAE 280A or B (Linear Systems Theory)
7. (To be determined by Executive Committee)

Elective Requirements: To encourage Ph.D. students specializing in computational science to both broaden themselves in an area of science or engineering as well as to obtain more specialized training in specific areas of computational science, students will be required to take and pass two elective courses from the following approved List B (four units per course), both of which must be outside of their home department, the first of which must be taken for a letter grade, and the second of which may be taken pass/fail. The CSME Executive Committee may approve the use of courses not appearing on the following list on a case-by-case basis. Courses taken to satisfy the elective requirements cannot count toward the qualifying requirements.

LIST B: Elective Graduate Courses in Mathematics, Science, and Engineering

1. Math. 270A-B-C (Numerical Analysis; not permitted for math. students, who typically take Math. 270A-B-C as a normal mathematics qualifying course.)
2. Math. 271A-B-C (Optimization)
3. Math. 272A-B-C (Advanced Numerical PDEs)
4. Math. 273A-B-C (Computational Mathematics Project)
5. Phys. 141/241 (Computational Physics I)
6. Phys. 142/242 (Computational Physics II)
7. Phys. 221 AB (Nonlinear dynamics)
8. Chem. 215 (Modeling Biological Macromolecules)
9. BGGN 260 (Neurodynamics)
10. (To be determined by Executive Committee)

Thesis/Dissertation: Students participating in the Ph.D in mathematics with a Specialization in Computational Science must complete a dissertation that meets all requirements for the regular Ph.D. in the home department. In addition, it is expected that the Ph.D. dissertation will be interdisciplinary in nature and involve some aspect of computational science.

Final Examination: Students participating in the Ph.D. in mathematics with a Specialization in Computational Science must meet the regular final examination requirements of the home department.

COURSES

For course descriptions not found in the UC San Diego General Catalog, 2010–11, please contact the department for more information.

All prerequisites listed below may be replaced by an equivalent or higher-level course. The listings of quarters in which courses will be offered are only tentative. Please consult the Department of Mathematics to determine the actual course offerings each year.

LOWER-DIVISION

3C. Pre-Calculus (4)
Functions and their graphs. Linear and polynomial functions, zeroes, inverse functions, exponential and logarithmic, trigonometric functions and their inverses. Emphasis on understanding algebraic, numerical and graphical approaches making use of graphing calculators. (No credit given if taken after Math. 4C, 1A/10A, or 2A/20A.) Three or more years of high school mathematics or equivalent recommended. **Prerequisite:** Math Placement Exam qualifying score.

4C. Pre-Calculus for Science and Engineering (4)
Review of polynomials. Graphing functions and relations: graphing rational functions, effects of linear changes of coordinates. Circular functions and right triangle trigonometry. Reinforcement of function concept: exponential, logarithmic, and trigonometric functions. Vectors. Conic sections. Polar coordinates. Three lectures, one recitation. (No credit given if taken after Math. 1A/10A or 2A/20A. Two units of credit given if taken after Math. 3C.) **Prerequisite:** Math Placement Exam qualifying score or Math. 3C with a grade of C– or better.

10A. Calculus (4)
Differentiation and integration of algebraic functions. Fundamental theorem of calculus. Applications. (No credit given if taken after Math. 20A). **Prerequisite:** Math Placement Exam qualifying score, or AP Calculus AB score of 2, or SAT II Math. Level 2 score of 600 or higher, or Math. 3C with a grade of C or better, or Math. 4C with a grade of C– or better.

10B. Calculus (4)
Further applications of the definite integral. Calculus of trigonometric, logarithmic, and exponential functions. Complex numbers. (No credit given if taken after Math. 2B/20B. Formerly numbered Math. 1B.) **Prerequisite:** AP Calculus AB score of 3, 4, or 5 (or equivalent AB subscore on BC exam), or Math. 10A with a grade of C– or better, or Math. 20A with a grade of C– or better.

10C. Calculus (4)
Vector geometry, velocity, and acceleration vectors. (No credit given if taken after Math. 2C/20C. Formerly numbered Math. 1C.) **Prerequisite:** AP Calculus BC score of 3, 4, or 5, or Math. 10B with a grade of C– or better, or Math. 20B with a grade of C– or better.

11. Elementary Probability and Statistics (4)
Events and probabilities, conditional probability, Bayes' formula. Discrete random variables: mean, variance; binomial, Poisson distributions. Continuous random variables: densities, mean, variance; normal, uniform, exponential distributions. Sample statistics, confidence intervals, hypothesis testing, regression. Applications. Intended for biology and social science majors. **Prerequisites:** AP Calculus BC score of 3, 4, or 5, or Math. 10B with a grade of C– or better, or Math. 20B with a grade of C– or better, and concurrent enrollment in Math. 11L.

11L. Elementary Probability and Statistics Laboratory (1)
Introduction to the use of software in probabilistic and statistical analysis. Emphasis on understanding connections between the theory of probability and statistics, numerical results of real data, and learning techniques of data analysis and interpretation useful for solving scientific problems. **Prerequisites:** AP Calculus BC score of 3, 4, or 5, or Math. 10B with a grade of C– or better, or Math. 20B with a grade of C– or better, and concurrent enrollment in Math. 11.

15A. Discrete Mathematics (4)
Basic discrete mathematical structures: sets, relations, functions, sequences, equivalence relations, partial orders, number systems. Methods of reasoning and proofs: propositional logic, predicate logic, induction, recursion, pigeonhole principle. Infinite sets and diagonalization. Basic counting techniques; permutations and combinations. Applications will be given to digital logic design, elementary number theory, design of programs, and proofs of program correctness. Equivalent to CSE 20. Credit not offered for both Math. 15A and CSE 20. **Prerequisites:** CSE 8A or CSE 8B or CSE 11. CSE 8B or CSE 11 may be taken concurrently with Math. 15A/CSE 20. (Not offered in 2010–11.)

15B. Mathematics for Algorithm and Systems (4)
This course introduces mathematical tools for the qualitative and quantitative analysis of algorithms and computer systems. Topics to be covered include basic enumeration and counting techniques; recurrence relations; graph theory; asymptotic notation; elementary applied discrete probability. Equivalent to CSE 21. Credit not offered for both Math. 15B and CSE 21. **Prerequisite:** Math. 15A or CSE 20 or 160A; CSE 12 is strongly recommended for CSE 21. (Not offered in 2010–11.)

20A. Calculus for Science and Engineering (4)
Foundations of differential and integral calculus of one variable. Functions, graphs, continuity, limits, derivative, tangent line. Applications with algebraic, exponential, logarithmic, and trigonometric functions. Introduction to the integral. (Two credits given if taken after Math. 1A/10A and no credit given if taken after Math. 1B/10B or Math. 1C/10C. Formerly numbered Math. 2A.) **Prerequisite:** Math Placement Exam qualifying score, or AP Calculus AB score of 2 or 3 (or equivalent AB subscore on BC exam), or SAT II Math. 2C score of 650 or higher, or Math. 4C with a grade of C– or better, or Math. 10A with a grade of C– or better.

20B. Calculus for Science and Engineering (4)
Integral calculus of one variable and its applications, with exponential, logarithmic, hyperbolic, and trigonometric functions. Methods of integration. Infinite series. Polar coordinates in the plane and complex exponentials. (Two units of credits given if taken after Math. 1B/10B or Math. 1C/10C.) **Prerequisite:** AP Calculus AB score of 4 or 5, or AP Calculus BC score of 3, or Math. 20A with a grade of C– or better, or Math. 10B with a grade of C– or better, or Math. 10C with a grade of C– or better.

20C. Calculus and Analytic Geometry for Science and Engineering (4)
Vector geometry, vector functions and their derivatives. Partial differentiation. Maxima and minima. Double integration, Two units of credit given if taken after Math. 10C. Credit not offered for both Math. 20C and 31BH. Formerly numbered Math. 21C. **Prerequisite:** AP Calculus BC score of 4 or 5, or Math. 20B with a grade of C– or better.

20D. Introduction to Differential Equations (4)
Ordinary differential equations: exact, separable, and linear; constant coefficients, undetermined coefficients, variations of parameters. Systems. Series solutions. Laplace transforms. Techniques for engineering sciences. Computing

symbolic and graphical solutions using Matlab. Formerly numbered Math. 21D. May be taken as repeat credit for Math. 21D. **Prerequisite:** Math. 20C (or Math. 21C) or Math. 31BH with a grade of C– or better.

20E. Vector Calculus (4)
Change of variable in multiple integrals, Jacobian, Line integrals, Green's theorem. Vector fields, gradient fields, divergence, curl. Spherical/cylindrical coordinates. Taylor series in several variables. Surface integrals, Stoke's theorem. Gauss' theorem. Conservative fields. Credit not offered for both Math. 20E and 31CH. **Prerequisite:** Math. 20C (or Math. 21C) or Math. 31BH with a grade of C– or better.

20F. Linear Algebra (4)
Matrix algebra, Gaussian elimination, determinants. Linear and affine subspaces, bases of Euclidean spaces. Eigenvalues and eigenvectors, quadratic forms, orthogonal matrices, diagonalization of symmetric matrices. Applications. Computing symbolic and graphical solutions using Matlab. Credit not offered for both Math. 20F and 31AH. **Prerequisite:** Math. 20C (or Math. 21C) with a grade of C– or better.

31AH. Honors Linear Algebra (4)
First quarter of three-quarter honors integrated linear algebra/multivariable calculus sequence for well-prepared students. Topics include: real/complex number systems, vector spaces, linear transformations, bases and dimension, change of basis, eigenvalues, eigenvectors, diagonalization. Credit not offered for both Math. 31AH and 20F. **Prerequisite:** AP Calculus BC score of 5 or consent of instructor.

31BH. Honors Multivariable Calculus (4)
Second quarter of three-quarter honors integrated linear algebra/multivariable calculus sequence for well-prepared students. Topics include: derivative in several variables, Jacobian matrices, extrema and constrained extrema, integration in several variables. Credit not offered for both Math. 31BH and 20C. **Prerequisite:** Math. 31AH with a grade of B– or better, or consent of instructor.

31CH. Honors Vector Calculus (4)
Third quarter of honors integrated linear algebra/multivariable calculus sequence for well-prepared students. Topics include: change of variables formula, integration of differential forms, exterior derivative, generalized Stoke's theorem, conservative vector fields, potentials. Credit not offered for both Math. 31CH and 20E. **Prerequisite:** Math. 31BH with a grade of B– or better, or consent of instructor.

87. Freshman Seminar (1)
The Freshman Seminar Program is designed to provide new students with the opportunity to explore an intellectual topic with a faculty member in a small seminar setting. Freshman seminars are offered in all campus departments and undergraduate colleges, and topics vary from quarter to quarter. Enrollment is limited to 15 to 20 students, with preference given to entering freshman. **Prerequisites:** none.

95. Introduction to Teaching Math (2)
(Cross-listed with EDS 30.) Revisit students' learning difficulties in mathematics in more depth to prepare students to make meaningful observations of how K–12 teachers deal with these difficulties. Explore how instruction can use students' knowledge to pose problems that stimulate students' intellectual curiosity. **Prerequisites:** none.

99R. Independent Study (1)
Independent study or research under direction of a member of the faculty. **Prerequisites:** Must be of first-year standing and a Regent's Scholar.

UPPER-DIVISION

100A. Abstract Algebra I (4)
First course in a rigorous three-quarter introduction to the methods and basic structures of higher algebra. Topics include: groups, subgroups and factor groups, homomorphisms, rings, fields. Students may not receive credit for both Math. 100A and Math. 103A. **Prerequisite:** Math. 31CH or Math. 109 or consent of instructor.

100B. Abstract Algebra II (4)
Second course in a rigorous three-quarter introduction to the methods and basic structures of higher algebra. Topics include: rings (especially polynomial rings) and ideals, unique factorization, fields; linear algebra from perspective of linear transformations on vector spaces, including inner product spaces, determinants, diagonalization. Students may not receive credit for both Math. 100B and Math. 103B. **Prerequisite:** Math. 100A or consent of instructor.

100C. Abstract Algebra III (4)
Third course in a rigorous three-quarter introduction to the methods and basic structures of higher algebra. Topics include: linear transformations, including Jordan canonical form and rational canonical form; Galois theory, including the insolvability of the quintic. **Prerequisite:** Math. 100B or consent of instructor. (F,W,S)

102. Applied Linear Algebra (4)
Second course in linear algebra from a computational yet geometric point of view. Elementary Hermitian matrices, Schur's theorem, normal matrices, and quadratic forms. Moore-Penrose generalized inverse and least square problems. Vector and matrix norms. Characteristic and singular values. Canonical forms. Determinants and multilinear algebra. **Prerequisite:** Math. 20F. or Math. 31AH. (W)

103A. Modern Algebra I (4)
First course in a two-quarter introduction to abstract algebra with some applications. Emphasis on group theory. Topics include: definitions and basic properties of groups, properties of isomorphisms, subgroups. Students may not receive credit for both Math. 100A and Math. 103A. **Prerequisite:** Math. 31CH or Math. 109 or consent of instructor.

103B. Modern Algebra II (4)
Second course in a two-quarter introduction to abstract algebra with some applications. Emphasis on rings and fields. Topics include: definitions and basic properties of rings, fields, and ideals, homomorphisms, irreducibility of polynomials. Students may not receive credit for both Math. 100B and Math. 103B. **Prerequisite:** Math. 103A or Math. 100A or consent of instructor.

104A. Number Theory I (4)
Elementary number theory with applications. Topics include unique factorization, irrational numbers, residue systems, congruences, primitive roots, reciprocity laws, quadratic forms, arithmetic functions, partitions, Diophantine equations, distribution of primes. Applications include fast Fourier transform, signal processing, codes, cryptography. **Prerequisite:** Math. 109 or Math. 31CH, or consent of instructor.

104B. Number Theory II (4)
Topics in number theory such as finite fields, continued fractions, Diophantine equations, character sums, zeta and theta functions, prime number theorem, algebraic integers, quadratic and cyclotomic fields, prime ideal theory, class number, quadratic forms, units, Diophantine approximation, *p*-adic numbers, elliptic curves. **Prerequisite:** Math. 104A or consent of instructor.

104C. Number Theory III (4)
Topics in algebraic and analytic number theory, with an advanced treatment of material listed for Math. 104B. **Prerequisite:** Math. 104B or consent of instructor.

107A-B. Computer Algebra (4-4)
An introduction to algebraic computation. Computational aspects of groups, rings, fields, etc. Data representation and algorithms for symbolic computation. Polynomials and their arithmetic. The use of a computer algebra system as an experimental tool in mathematics. Programming using algebra systems. **Prerequisite:** prior or concurrent enrollment in the Math. 100 or 103 sequence. (Not offered in 2010–11.)

109. Mathematical Reasoning (4)
This course uses a variety of topics in mathematics to introduce the students to rigorous mathematical proof, emphasizing quantifiers, induction, negation, proof by contradiction, naive set theory, equivalence relations and epsilon-delta proofs. Required of all departmental majors. **Prerequisite:** Math. 20F or Math 31AH or consent of instructor.

110A. Introduction to Partial Differential Equations (4)
Fourier series, orthogonal expansions, and eigenvalue problems. Sturm-Liouville theory. Separation of variables for partial differential equations of mathematical physics, including topics on Bessel functions and Legendre polynomials. Formerly Math. 110. Students may not receive credit for Math. 110A and Math. 110. **Prerequisites:** Math. 20D and either 20F or Math. 31AH, or consent of instructor. (F,S)

110B. Elements of Partial Differential Equations and Integral Equations (4)
Basic concepts and classification of partial differential equations. First order equations, characteristics. Hamilton-Jacobi theory, Laplace's equation, wave equation, heat equation. Separation of variables, eigenfunction expansions, existence and uniqueness of solutions. Formerly Math. 132A. Students may not receive credit for Math. 110B and Math. 132A. **Prerequisite:** Math. 110A or consent of instructor. (W)

111A. Mathematical Modeling I (4)
An introduction to mathematical modeling in the physical and social sciences. Topics vary, but have included mathematical models for epidemics, chemical reactions, political organizations, magnets, economic mobility, and geographical distributions of species. May be repeated for credit when topics change. **Prerequisites:** Math. 20D and either Math. 20F or Math. 31AH, or consent of instructor.

111B. Mathematical Modeling II (4)
Continued study on mathematical modeling in the physical and social sciences, using advanced techniques that will expand upon the topics selected and further the mathematical theory presented in Math. 111A. May be repeated for credit when topics change. **Prerequisite:** Math. 111A or consent of instructor.

120A. Elements of Complex Analysis (4)
Complex numbers and functions. Analytic functions, harmonic functions, elementary conformal mappings. Complex integration. Power series. Cauchy's theorem. Cauchy's formula. Residue theorem. **Prerequisite**: Math. 20E or Math. 31CH, or consent of instructor. (F,W)

120B. Applied Complex Analysis (4)
Applications of the residue theorem. Conformal mapping and applications to potential theory, flows, and temperature distributions. Fourier transformations. Laplace transformations, and applications to integral and differential equations. Selected topics such as Poisson's formula, Dirichlet's problem, Neumann's problem, or special functions. **Prerequisite:** Math. 120A. (W,S)

121A. Foundations of Teaching and Learning Mathematics I (4)
(Cross-listed with EDS 121A.) Develop teachers' knowledge base (knowledge of mathematics content, pedagogy, and student learning) in the context of advanced mathematics. This course builds on the previous courses where these components of knowledge were addressed exclusively in the context of high-school mathematics. **Prerequisites:** EDS 30/Math. 95, Calculus 10C or 20C.

121B. Foundations of Teaching and Learning Math II (4)
(Cross-listed with EDS 121B.) Examine how learning theories can consolidate observations about conceptual development with the individual student as well as the development of knowledge in the history of mathematics. Examine how teaching theories explain the effect of teaching approaches addressed in the previous courses. **Prerequisite:** EDS 121A/Math. 121A.

130A. Ordinary Differential Equations I (4)
Linear and nonlinear systems of differential equations. Stability theory, perturbation theory. Applications and introduction to numerical solutions. Three lectures. **Prerequisites:** Math. 20D and either Math. 20F or Math. 31AH or consent of instructor. (F)

130B. Ordinary Differential Equations II (4)
Existence and uniqueness of solutions to differential equations. Local and global theorems of continuity and differentiabillity. Three lectures. **Prerequisite:** Math. 130A or consent of instructor. (W)

131. Variational Methods in Optimization (4)
Maximum-minimum problems. Normed vector spaces, functionals, Gateaux variations. Euler-Lagrange multiplier theorem for an extremum with constraint. Calculus of variations via the multiplier theorem. Applications taken from a variety of areas: applied mechanics, economics, astronautics physics, geometry, control theory. **Prerequisite:** Math. 20F or Math. 31AH, or consent of instructor. (S)

140A. Foundations of Real Analysis I (4)
First course in a rigorous three-quarter sequence on real analysis. Topics include: the real number system, basic topology, numerical sequences and series, continuity. Students may not receive credit for both Math. 140A and Math. 142A. **Prerequisite:** Math. 31CH or Math. 109, or consent of instructor.

140B. Foundations of Real Analysis II (4)
Second course in a rigorous three-quarter sequence on real analysis. Topics include: differentiation, the Riemann-Stieltjes integral, sequences and series of functions, power series, Fourier series, and special functions. Students may not receive credit for both Math. 140B and Math. 142B. **Prerequisite:** Math. 140A or consent of instructor.

140C. Foundations of Real Analysis III (4)
Third course in a rigorous three-quarter sequence on real analysis. Topics include: differentiation of functions of several real variables, the implicit and inverse function theorems, the Lebesgue integral, infinite-dimensional normed spaces. **Prerequisite:** Math. 140B or consent of instructor.

142A. Introduction to Analysis I (4)
First course in an introductory two-quarter sequence on analysis. Topics include: the real number system, numerical sequences and series, limits of functions, continuity. Students may not receive credit for both Math. 140 and Math. 142A. **Prerequisite:** Math. 31CH or Math. 109, or consent of instructor.

142B. Introduction to Analysis II (4)
Second course in an introductory two-quarter sequence on analysis. Topics include: differentiation, the Rieman integral, sequences and series of functions, uniform convergence, Taylor and Fourier series, special functions. Students may not receive credit for both Math. 140B and Math. 142B. **Prerequisites:** Math. 142A or Math. 140A, or consent of instructor.

150A. Differential Geometry (4)
Differential geometry of curves and surfaces. Gauss and mean curvatures, geodesics, parallel displacement, Gauss-Bonnet theorem. Three lectures. **Prerequisites:** Math. 20E with a grade of C– or better and Math. 20F with a grade of C– or better, or consent of instructor. (F)

150B. Calculus on Manifolds (4)
Calculus of functions of several variables, inverse function theorem. Further topics may include exterior differential forms, Stokes' theorem, manifolds, Sard's theorem, elements of differential topology, singularities of maps, catastrophes, further topics in differential geometry, topics in geometry of physics. **Prerequisite:** Math. 150A or consent of instructor. (W)

152. Applicable Mathematics and Computing (4)
This course will give students experience in applying theory to real world applications such as Internet and wireless communication problems. The course will incorporate talks by experts from industry and students will be helped to carry out independent projects. Topics include graph visualization, labelling, and embeddings, random graphs and randomized algorithms. May be taken 3 times for credit. **Prerequisites:** Math. 20D and either 20F or Math. 31AH, or consent of instructor.

153. Geometry for Secondary Teachers (4)
Two- and three-dimensional Euclidean geometry is developed from one set of axioms. Pedagogical issues will emerge from the mathematics and be addressed using current research in teaching and learning geometry. This course is designed for prospective secondary school mathematics teachers. **Prerequisite:** Math. 109 or Math. 31CH, or consent of instructor.

154. Discrete Mathematics and Graph Theory (4)
Basic concepts in graph theory. Combinatorial tools, structures in graphs (Hamiltonian cycles, perfect matching). Properties of graphics and applications in basic algorithmic problems (planarity, k-colorability, traveling salesman problem). **Prerequisites:** Math. 109 or Math. 31CH, or consent of instructor.

155A. Computer Graphics (4)
Bezier curves and control lines, de Casteljau construction for subdivision, elevation of degree, control points of Hermite curves, barycentric coordinates, rational curves. Programming knowledge recommended. Students may not receive credit for both Math. 155A and CSE 167. **Prerequisite:** Math. 20F or Math. 31AH, or consent of instructor. (F)

155B. Topics in Computer Graphics (4)
Spline curves, spline interpolation, affine and affine cross ratios, polar forms (blossoming), the Oslo algorithm for knot insertion, NURBS and geometric continuity. **Prerequisite:** Math. 155A or consent of instructor. (W)

163. History of Mathematics (4)
Topics will vary from year to year in areas of mathematics and their development. Topics may include the evolution of mathematics from the Babylonian period to the eighteenth century using original sources, a history of the foundations of mathematics and the development of modern mathematics. **Prerequisite:** Math. 20B or consent of instructor. (S)

166. Intro to the Theory of Computation (4)
Introduction to formal languages; regular languages; regular expressions, finite automata, minimization, closure properties, decision algorithms, and non-regular languages; context-free languages, context-free grammars, push-down automata, parsing theory, closure properties, and noncontext-free languages; computable languages; turing machines, recursive functions, Church's thesis, undecidability and the halting problem. Equivalent to CSE 105. **Prerequisites:** CSE 8B or 9B or 10 or 65 or 62B AND CSE 20 or 160A or Math. 15A or 109 or 100A or 103A. (Not offered in 2010–11.)

168A. Topics in Applied Mathematics–Computer Science (4)
Topics to be chosen in areas of applied mathematics and mathematical aspects of computer science. May be repeated once for credit with different topics. **Prerequisite:** Math. 20F or Math. 31AH, or consent of instructor. (W,S)

170A. Introduction to Numerical Analysis: Linear Algebra (4)
Analysis of numerical methods for linear algebraic systems and least squares problems. Orthogonalization methods. Ill conditioned problems. Eigenvalue and singular value computations. Three lectures, one recitation. Knowledge of programming recommended. **Prerequisite:** Math. 20F. (F,S)

170B. Introduction to Numerical Analysis: Approximation and Nonlinear Equations (4)
Rounding and discretization errors. Calculation of roots of polynomials and nonlinear equations. Interpolation. Approximation of functions. Three lectures, one recitation. Knowledge of programming recommended. **Prerequisite:** Math. 170A. (W)

170C. Numerical Ordinary Differential Equations (4)
Numerical differentiation and integration. Ordinary differential equations and their numerical solution. Basic existence and stability theory. Difference equations. Boundary value problems. Three lectures, one recitation. **Prerequisite:** Math. 170B or consent of instructor. (S)

171A. Introduction to Numerical Optimization: Linear Problems (4)
Linear optimization and applications. Linear programming, the simplex method, duality. Selected topics from integer programming, network flows, transportation problems, inventory problems, and other applications. Three lectures, one recitation. Knowledge of programming recommended. Credit not allowed for both Math. 171A and Econ. 172A. **Prerequisite:** Math. 20F.

171B. Introduction to Numerical Optimization: Nonlinear Problems (4)
Convergence of sequences in Rn, multivariate Taylor series. Bisection and related methods for nonlinear equations in one variable. Newton's methods for nonlinear equations in one and many variables. Unconstrained optimization and Newton's method. Equality-constrained optimization, Kuhn-Tucker theorem. Inequality-constrained optimization. Three lectures, one recitation. Knowledge of programming recommended. Credit not allowed for both Math. 171B and Econ. 172B. **Prerequisite:** Math. 171A.

174. Numerical Methods for Physical Modeling (4)
(Conjoined with Math. 274) Floating point arithmetic, direct and iterative solution of linear equations, iterative solution of nonlinear equations, optimization, approximation theory, interpolation, quadrature, numerical methods for initial and boundary value problems in ordinary differential equations. Students may not receive credit for both Math. 174 and PHYS 105, AMES 153 or 154. Students may not receive credit for Math. 174 if Math. 170A, B, or C has already been taken. Graduate students will do an extra assignment/exam. **Prerequisites:** Math. 20D or Math. 21D, and either Math. 20F or Math 31AH, or consent of instructor.

175. Numerical Methods for Partial Differential Equations (4)
(Conjoined with Math. 275.) Mathematical background for working with partial differential equations. Survey of finite difference, finite element, and other numerical methods for the solution of elliptic, parabolic, and hyperbolic partial differential equations. Formerly Math. 172; students may not receive credit for Math. 175/275 and Math. 172. Graduate students do an extra paper, project, or presentation, per instructor. **Prerequisite:** Math. 174 or Math. 274, or consent of instructor.

176. Advanced Data Structures (4)
Descriptive and analytical presentation of data structures and algorithms. Lists, tables, priority queues, disjoint subsets, and dictionaries data types. Data structuring techniques include linked lists, arrays, hashing, and trees. Performance evaluation involving worst case, average and expected case, and amortized analysis. Credit not offered for both Math. 176 and CSE 100. Equivalent to CSE 100. **Prerequisites:** CSE 12, CSE 21, or Math. 15B, and CSE 30, or consent of instructor. Not offered in 2010–11.

179. Projects in Computational and Applied Mathematics (4)
(Conjoined with Math. 279.) Mathematical models of physical systems arising in science and engineering, good models and well-posedness, numerical and other approximation techniques, solution algorithms for linear and nonlinear approximation problems, scientific visualizations, scientific software design and engineering, project-oriented. Graduate students will do an extra paper, project, or presentation per instructor. **Prerequisite:** Math. 174 or Math. 274 or consent of instructor.

180A. Introduction to Probability (4)
Probability spaces, random variables, independence, conditional probability, distribution, expectation, variance, joint distributions, central limit theorem. (Two units of credit offered for Math. 180A if Econ. 120A previously, no credit offered if Econ. 120A concurrently.) **Prerequisite:** Math. 20C or Math. 31BH, or consent of instructor. (F)

180B. Introduction to Stochastic Processes I (4)
Random vectors, multivariate densities, covariance matrix, multivariate normal distribution. Random walk, Poisson process. Other topics if time permits. Three lectures. **Prerequisites:** Math. 20D and either Math. 20F or Math 31AH, and Math. 180A, or consent of instructor. (W)

180C. Introduction to Stochastic Processes II (4)
Markov chains in discrete and continuous time, random walk, recurrent events. If time permits, topics chosen from stationary normal processes, branching processes, queuing theory. Three lectures. **Prerequisite:** Math. 180B or consent of instructor. (S)

181A. Introduction to Mathematical Statistics I (4)
Multivariate distribution, functions of random variables, distributions related to normal. Parameter estimation, method of moments, maximum likelihood. Estimator

accuracy and confidence intervals. (Two units of credit offered for Math. 181A if Econ. 120B previously, no credit offered if Econ. 120B concurrently.) **Prerequisites:** Math. 180A or Econ. 120A, and Math. 20F or Math. 31AH, or consent of instructor. (W)

181B. Introduction to Mathematical Statistics II (4)
Hypothesis testing. Linear models, regression, and analysis of variance. Goodness of fit tests. Nonparametric statistics. **Prerequisite:** Math. 181A or consent of instructor. (S)

181C. Mathematical Statistics—Nonparametric Statistics (4)
Topics covered may include the following: classical rank test, rank correlations, permutation tests, distribution free testing, efficiency, confidence intervals, nonparametric regression and density estimation, resampling techniques (bootstrap, jackknife, etc.) and cross validations. **Prerequisite:** Math. 181B or consent of instructor.

181E. Mathematical Statistics—Time Series (4)
Analysis of trends and seasonal effects, autoregressive and moving averages models, forecasting, informal introduction to spectral analysis. **Prerequisite:** Math. 181B or consent of instructor.

183. Statistical Methods (4)
Introduction to probability. Discrete and continuous random variables–binomial, Poisson and Gaussian distributions. Central limit theorem. Data analysis and inferential statistics: graphical techniques, confidence intervals, hypothesis tests, curve fitting. (Credit not offered for Math. 183 if Econ. 120A, ECE 109, Math. 180A, Math. 181A, or Math. 186 previously or concurrently taken.) **Prerequisite:** Math. 20C (21C) with a grade of C– or better, or consent of instructor. (F,S)

184A. Combinatorics (4)
Introduction to the theory and applications of combinatorics. Enumeration of combinatorial structures. Ranking and unranking. Graph theory with applications and algorithms. Recursive algorithms. Inclusion-exclusion. Generating functions. Polya theory. **Prerequisite:** Math. 109 with a grade of C– or better, or consent of instructor. (W,S)

185. Introduction to Computational Statistics (4)
Statistical analysis of data by means of package programs. Regression, analysis of variance, discriminant analysis, principal components, Monte Carlo simulation, and graphical methods. Emphasis will be on understanding the connections between statistical theory, numerical results, and analysis of real data. **Prerequisites:** Math. 181B with a grade of C– or better, or concurrent enrollment.

186. Probability Statistics for Bioinformatics (4)
This course will cover discrete and random variables, data analysis and inferential statistics, likelihood estimators and scoring matrices with applications to biological problems. Introduction to Binomial, Poisson, and Gaussian distributions, central limit theorem, applications to sequence and functional analysis of genomes and genetic epidemiology. (Credit not offered for Math. 186 if Econ. 120A, ECE 109, Math. 180A, Math. 181A, or Math. 183 previously or concurrently.) **Prerequisites:** Math. 20C (21C) with a grade of C– or better, or consent of instructor.

187. Introduction to Cryptography (4)
An introduction to the basic concepts and techniques of modern cryptography. Classical cryptanalysis. Probabilistic models of plaintext. Monalphabetic and polyalphabetic substitution. The one-time system. Caesar-Vigenere-Playfair-Hill substitutions. The Enigma. Modern-day developments. The Data Encryption Standard. Public key systems. Security aspects of computer networks. Data protection. Electronic mail. Three lectures, one recitation. **Prerequisite:** programming experience. (S)

188. Design and Analysis of Algorithms (4)
Introduction to the design and analysis of efficient algorithms. Basic techniques for analyzing the time requirements of algorithms. Algorithms for sorting, searching, and pattern matching, algorithms for graphs and networks. NP-complete problems. Equivalent to CSE 101. **Prerequisites:** CSE 100 or Math. 176A for Math. 188; CSE 12, CSE 21, and CSE 100 for CSE 101. (Not offered in 2010–11.)

190. Introduction to Topology (4)
Topological spaces, subspaces, products, sums and quotient spaces. Compactness, connectedness, separation axioms. Selected further topics such as fundamental group, classification of surfaces, Morse theory, topological groups. May be repeated for credit once when topics vary, with consent of instructor. Three lectures. **Prerequisite:** Math. 109 or Math 31CH, or consent of instructor. (W)

191. Topics in Topology (4)
Topics to be chosen by the instructor from the fields of differential algebraic, geometric, and general topology. Three lectures. **Prerequisite:** Math. 190 or consent of instructor. (S)

192. Senior Seminar in Mathematics (1)
The Senior Seminar Program is designed to allow senior undergraduates to meet with faculty members in a small group setting to explore an intellectual topic in mathematics at the upper-division level. Topics will vary from quarter to quarter. Senior seminars may be taken for credit up to four times, with a change in topic, and permission of the department. Enrollment is limited to twenty students, with preference given to seniors. **Prerequisites:** department stamp and/or consent of instructor.

193A. Actuarial Mathematics I (4)
Probabilistic Foundations of Insurance. Short-term risk models. Survival distributions and life tables. Introduction to life insurance. **Prerequisite:** Math. 180A or Math. 183, or consent of instructor.

193B. Actuarial Mathematics II (4)
Life Insurance and Annuities. Analysis of premiums and premium reserves. Introduction to multiple life functions and decrement models as time permits. **Prerequisite:** Math. 193A or consent of instructor.

194. The Mathematics of Finance (4)
Introduction to the mathematics of financial models. Basic probabilistic models and associated mathematical machinery will be discussed, with emphasis on discrete time models. Concepts covered will include conditional expectation, martingales, optimal stopping, arbitrage pricing, hedging, European and American options. **Prerequisites::** Math. 20D, and either Math. 20F or Math. 31AH, and either Math. 180A or Math. 183, or consent of instructor.

195. Introduction to Teaching in Mathematics (4)
Students will be responsible for and teach a class section of a lower-division mathematics course. They will also attend a weekly meeting on teaching methods. (Does not count towards a minor or major.) Five lectures, one recitation. **Prerequisite:** consent of instructor. (F,W,S)

196. Student Colloquium (1)
A variety of topics and current research results in mathematics will be presented by guest lecturers and students under faculty direction. May be taken for P/NP grade only. **Prerequisite:** upper-division status.

197. Mathematics Internship (2 or 4)
An enrichment program which provides work experience with public/private sector employers. Subject to the availability of positions, students will work in a local company under the supervision of a faculty member and site supervisor. Units may not be applied towards major graduation requirements. **Prerequisites:** completion of 90 units, 2 upper-division mathematics courses, an overall 2.5 UCSD G.P.A., consent of mathematics faculty coordinator, and submission of written contract. Department stamp required.

199. Independent Study for Undergraduates (2 or 4)
Independent reading in advanced mathematics by individual students. Three periods. (P/NP grades only.) **Prerequisite:** permission of department. (F,W,S)

199H. Honors Thesis Research for Undergraduates (2–4)
Honors thesis research for seniors participating in the Honors Program. Research is conducted under the supervision of a mathematics faculty member. **Prerequisites:** admission to the Honors Program in mathematics, department stamp.

GRADUATE

200A-B-C. Algebra (4-4-4)
Group actions, factor groups, polynomial rings, linear algebra, rational and Jordan canonical forms, unitary and Hermitian matrices, Sylow theorems, finitely generated abelian groups, unique factorization, Galois theory, solvability by radicals, Hilbert Basis Theorem, Hilbert Nullstellensatz, Jacobson radical, semisimple Artinian rings. **Prerequisite:** consent of instructor.

201A-B. Basic Topics in Algebra (4-4)
Recommended for all students specializing in algebra. Basic topics include categorical algebra, commutative algebra, group representations, homological algebra, nonassociative algebra, ring theory. **Prerequisites:** Math. 200A-B-C or consent of instructor. (F,W,S)

202A. Applied Algebra I (4)
Introduction to algebra from a computational perspective. Groups, rings, linear algebra, rational and Jordan forms, unitary and Hermitian matrices, matrix decompositions, perturbation of eigenvalues, group representations, symmetric functions, fast Fourier transform, commutative algebra, Grobner basis, finite fields. **Prerequisite:** graduate standing or consent of instructor.

202B. Applied Algebra II (4)
Second course in algebra from a computational perspective. Groups, rings, linear algebra, rational and Jordan forms, unitary and Hermitian matrices, matrix decompositions, perturbation of eigenvalues, group representations, symmetric functions, fast Fourier transform, commutative algebra, Grobner basis, finite fields. **Prerequisite:** Math. 202A or consent of instructor.

202C. Applied Algebra III (4)
Third course in algebra from a computational perspective. Groups, rings, linear algebra, rational and Jordan forms, unitary and Hermitian matrices, matrix decompositions, perturbation of eigenvalues, group representations, symmetric functions, fast Fourier transform, commutative algebra, Grobner basis, finite fields. **Prerequisite:** Math. 202B or consent of instructor.

203A-B-C. Algebraic Geometry (4-4-4)
Places, Hilbert Nullstellensatz, varieties, product of varieties: correspondences, normal varieties. Divisors and linear systems; Riemann-Roch theorem; resolution of singularities of curves. Grothendieck schemes; cohomology, Hilbert schemes; Picard schemes. **Prerequisites:** Math. 200A-B-C. (F,W,S)

204. Topics in Number Theory (4)
Topics in analytic number theory, such as zeta functions and L-functions and the distribution of prime numbers, zeros of zeta functions and Siegel's theorem, transcendence theory, modular forms, finite and infinite symmetric spaces. **Prerequisite:** consent of instructor.

205. Topics in Algebraic Number Theory (4)
Topics in algebraic number theory, such as cyclotomic and Kummer extensions, class number, units, splitting of primes in extensions, zeta functions of number fields and the Brauer-Siegel Theorem, class field theory, elliptic curves and curves of higher genus, complex multiplication. **Prerequisite:** consent of instructor.

207A-B-C. Topics in Algebra (4-4-4)
In recent years, topics have included number theory, commutative algebra, noncommutative rings, homological algebra, and Lie groups. May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

208. Seminar in Algebra (1)
Various topics in algebra. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

209. Seminar in Number Theory (1)
Various topics in number theory. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

210A. Mathematical Methods in Physics and Engineering (4)
Complex variables with applications. Analytic functions, Cauchy's theorem, Taylor and Laurent series, residue theorem and contour integration techniques, analytic continuation, argument principle, conformal mapping,

potential theory, asymptotic expansions, method of steepest descent. **Prerequisites:** Math. 20DEF, 140A/142A or consent of instructor.

210B. Mathematical Methods in Physics and Engineering (4)
Linear algebra and functional analysis. Vector spaces, orthonormal bases, linear operators and matrices, eigenvalues and diagonalization, least squares approximation, infinite-dimensional spaces, completeness, integral equations, spectral theory, Green's functions, distributions, Fourier transform. **Prerequisite:** Math. 210A or consent of instructor. (W)

210C. Mathematical Methods in Physics and Engineering (4)
Calculus of variations: Euler-Lagrange equations, Noether's theorem. Fourier analysis of functions and distributions in several variables. Partial differential equations: Laplace, wave, and heat equations; fundamental solutions (Green's functions); well-posed problems. **Prerequisite:** Math. 210B or consent of instructor. (S)

212A. Introduction to the Mathematics of Systems and Control (4)
Linear and nonlinear systems, and their input-output behavior, linear continuous time and discrete-time systems, reachability and controllability for linear systems, feedback and stabilization, eigenvalue placement, nonlinear controllability, feedback linearization, disturbance rejection, nonlinear stabilization, Lyapunov and control-Lyapunov functions, linearization principle for stability. **Prerequisites:** Math. 102 or equivalent, Math. 120A or equivalent, Math. 142A or equivalent.

212B. Introduction to the Mathematics of Systems and Control (4)
Observability notions, linearization principle for observability. Realization theory for linear systems, observers and dynamic feedback, detectability, external stability for linear systems, frequency-domain considerations, dynamic programming, quadratic cost, state estimation and Kalman filtering, nonlinear stabilizing optimal controls, calculus of variations, and the Maximum Principle. **Prerequisite:** Math. 212A.

212C. Introduction to the Mathematics of Systems and Control (4)
Topics of current interest on systems theory, control, and estimation to be chosen by instructor. **Prerequisite:** Math. 212B.

216. Topics in Pure Mathematics (4)
This course brings together graduate students, postdocs, and faculty to examine a current research topic of broad interest. Previously covered topics include: noncommutative geometry, Loop groups, geometric quantization. **Prerequisite:** consent of instructor.

217A. Topics in Applied Mathematics (4)
In recent years, topics have included applied complex analysis, special functions, and asymptotic methods. May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

220A-B-C. Complex Analysis (4-4-4)
Complex numbers and functions. Cauchy theorem and its applications, calculus of residues, expansions of analytic functions, analytic continuation, conformal mapping and Riemann mapping theorem, harmonic functions. Dirichlet principle, Riemann surfaces. **Prerequisites:** Math. 140A-B or consent of instructor. (F,W,S)

221A-B. Topics in Several Complex Variables (4-4)
Formal and convergent power series, Weierstrass preparation theorem; Cartan-Ruckert theorem, analytic sets; mapping theorems; domains of holomorphy; proper holomorphic mappings; complex manifolds; modifications. **Prerequisites:** Math. 200A and 220A-B-C or consent of instructor.

231A-B-C. Partial Differential Equations (4-4-4)
Existence and uniqueness theorems. Cauchy-Kowalewski theorem, first order systems. Hamilton-Jacobi theory, initial value problems for hyperbolic and parabolic systems, boundary value problems for elliptic systems. Green's function, eigenvalue problems, perturbation theory. **Prerequisites:** Math. 210A-B or 240A-B-C or consent of instructor.

237A-B. Topics in Differential Equations (4-4)
May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

240A-B-C. Real Analysis (4-4-4)
Lebesgue integral and Lebesgue measure, Fubini theorems, functions of bounded variations, Stieltjes integral, derivatives and indefinite integrals, the spaces L and C, equi-continuous families, continuous linear functionals general measures and integrations. **Prerequisites:** Math. 140A-B-C. (F,W,S)

241A-B. Functional Analysis (4-4)
Metric spaces and contraction mapping theorem; closed graph theorem; uniform boundedness principle; Hahn-Banach theorem; representation of continuous linear functionals; conjugate space, weak topologies; extreme points; Krein-Milman theorem; fixed-point theorems; Riesz convexity theorem; Banach algebras. **Prerequisites:** Math. 240A-B-C or consent of instructor.

242. Topics in Fourier Analysis (4)
A course on Fourier analysis in Euclidean spaces, groups, symmetric spaces. **Prerequisites:** Math. 240A-B-C or consent of instructor.

245A. Convex Analysis and Optimization I (4)
Convex sets and functions, convex and affine hulls, relative interior, closure, and continuity, recession and existence of optimal solutions, saddle point and min-max theory, subgradients and subdifferentials. **Prerequisites:** Math. 20F and Math. 142A, or graduate standing, or consent of instructor.

245B. Convex Analysis and Optimization II (4)
Optimality conditions, strong duality and the primal function, conjugate functions, Fenchel duality theorems, dual derivatives and subgradients, subgradient methods, cutting plane methods. **Prerequisite:** Math. 245A or consent of instructor.

245C. Convex Analysis and Optimization III (4)
Convex optimization problems, linear matrix inequalities, second-order cone programming, semidefinite programming, sum of squares of polynomials, positive polynomials, distance geometry. **Prerequisite:** Math. 245B or consent of instructor.

247A-B-C. Topics in Real Analysis (4-4-4)
In recent years, topics have included Fourier analysis, distribution theory, martingale theory, operator theory. May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

248. Seminar in Real Analysis (1)
Various topics in real analysis. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

250A-B-C. Differential Geometry (4-4-4)
Differential manifolds, Sard theorem, tensor bundles, Lie derivatives, DeRham theorem, connections, geodesics, Riemannian metrics, curvature tensor and sectional curvature, completeness, characteristic classes. Differential manifolds immersed in Euclidean space. **Prerequisite:** consent of instructor. (F,W,S)

251A-B-C. Lie Groups (4-4-4)
Lie groups, Lie algebras, exponential map, subgroup subalgebra correspondence, adjoint group, universal enveloping algebra. Structure theory of semi-simple Lie groups, global decompositions, Weyl group. Geometry and analysis on symmetric spaces. **Prerequisites:** Math. 200 and 250 or consent of instructor. (F,W,S)

256. Seminar in Lie Groups and Lie Algebras (1)
Various topics in Lie groups and Lie algebras, including structure theory, representation theory, and applications. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.) (F,W,S)

257A. Topics in Differential Geometry (4)
In recent years, topics have included Morse theory and general relativity. May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

257B. Topics in Differential Geometry (4)
In recent years, topics have included Morse theory and general relativity. May be repeated for credit with consent of advisor. Math. 257A must be taken before Math. 257B. **Prerequisite:** consent of instructor.

257C. Topics in Differential Geometry (4)
In recent years, topics have included Morse theory and general relativity. May be repeated for credit with consent of advisor. Math. 257B must be taken before Math. 257C. **Prerequisite:** consent of instructor.

258. Seminar in Differential Geometry (1)
Various topics in differential geometry. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

259A-B-C. Geometrical Physics (4-4-4)
Manifolds, differential forms, homology, deRham's theorem. Riemannian geometry, harmonic forms. Lie groups and algebras, connections in bundles, homotopy sequence of a bundle, Chern classes. Applications selected from Hamiltonian and continuum mechanics, electromagnetism, thermodynamics, special and general relativity, Yang-Mills fields. **Prerequisite:** graduate standing in mathematics, physics, or engineering, or consent of instructor.

260A. Mathematical Logic I (4)
Propositional calculus and first-order logic. Theorem proving, Model theory, soundness, completeness, and compactness, Herbrand's theorem, Skolem-Lowenheim theorems, Craig interpolation. **Prerequisite:** graduate standing or consent of instructor.

260B. Mathematical Logic II (4)
Theory of computation and recursive function theory, Church's thesis, computability and undecidability. Feasible computability and complexity. Peano arithmetic and the incompleteness theorems, nonstandard models. **Prerequisite:** Math. 260A or consent of instructor.

261A. Probabilistic Combinatorics and Algorithms (4)
Introduction to the probabilistic method. Combinatorial applications of the linearity of expectation, second moment method, Markov, Chebyschev, and Azuma inequalities, and the local limit lemma. Introduction to the theory of random graphs. **Prerequisite:** graduate standing or consent of instructor.

261B. Probabilistic Combinatorics and Algorithms II (4)
Introduction to probabilistic algorithms. Game theoretic techniques. Applications of the probabilistic method to algorithm analysis. Markov Chains and Random walks. Applications to approximation algorithms, distributed algorithms, online and parallel algorithms. Math. 261A must be taken before Math. 261B. **Prerequisite:** Math. 261A.

261C. Probabilistic Combinatorics and Algorithms III (4)
Advanced topics in the probabilistic combinatorics and probabilistics algorithms. Random graphs. Spectral Methods. Network algorithms and optimization. Statistical learning. Math. 261B must be taken before Math. 261C. **Prerequisite:** Math. 261B.

262A-B-C. Topics in Combinatorial Mathematics (4-4-4)
Development of a topic in combinatorial mathematics starting from basic principles. Problems of enumeration, existence, construction, and optimization with regard to finite sets. Some familiarity with computer programming desirable but not required. **Prerequisites:** Math. 100A-B-C.

264A-B-C. Combinatorics (4-4-4)
Topics from partially ordered sets, Mobius functions, simplicial complexes and shell ability. Enumeration, formal power series and formal languages, generating functions, partitions. Lagrange inversion, exponential structures, combinatorial species. Finite operator methods, q-analogues, Polya theory, Ramsey theory. Representation theory of the symmetric group, symmetric functions and operations with Schur functions. (F,W,S)

269. Seminar in Combinatorics (1)
Various topics in combinatorics. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

270A. Numerical Linear Algebra (4)
Error analysis of the numerical solution of linear equations and least squares problems for the full rank and rank deficient cases. Error analysis of numerical methods for eigenvalue problems and singular value problems. Iterative methods for large sparse systems of linear equations. **Prerequisites:** graduate standing or consent of instructor.

270B. Numerical Approximation and Nonlinear Equations (4)
Iterative methods for nonlinear systems of equations, Newton's method. Unconstrained and constrained optimization. The Weierstrass theorem, best uniform approximation, least-squares approximation, orthogonal polynomials. Polynomial interpolation, piecewise polynomial interpolation, piecewise uniform approximation. Numerical differentiation: divided differences, degree of precision. Numerical quadrature: interpolature quadrature, Richardson extrapolation, Romberg Integration, Gaussian quadrature, singular integrals, adaptive quadrature. **Prerequisites:** Math. 270A or consent of instructor.

270C. Numerical Ordinary Differential Equations (4)
Initial value problems (IVP) and boundary value problems (BVP) in ordinary differential equations. Linear methods for IVP: one and multistep methods, local truncation error, stability, convergence, global error accumulation. Runge-Kutta (RK) Methods for IVP: RK methods, predictor-corrector methods, stiff systems, error indicators, adaptive time-stepping. Finite difference, finite volume, collocation, spectral, and finite element methods for BVP; a priori and a posteriori error analysis, stability, convergence, adaptivity. **Prerequisites:** Math. 270B or consent of instructor.

271A-B-C. Numerical Optimization (4-4-4)
Formulation and analysis of algorithms for constrained optimization. Optimality conditions; linear and quadratic programming; interior methods; penalty and barrier function methods; sequential quadratic programming methods. **Prerequisite:** consent of instructor. (F,W,S)

272A. Numerical Partial Differential Equations I (4)
Survey of discretization techniques for elliptic partial differential equations, including finite difference, finite element and finite volume methods. Lax-Milgram Theorem and LBB stability. A priori error estimates. Mixed methods. Convection-diffusion equations. Systems of elliptic PDEs. **Prerequisites:** graduate standing or consent of instructor.

272B. Numerical Partial Differential Equations II (4)
Survey of solution techniques for partial differential equations. Basic iterative methods. Preconditioned conjugate gradients. Multigrid methods. Hierarchical basis methods. Domain decomposition. Nonlinear PDEs. Sparse direct methods. **Prerequisites:** Math. 272A or consent of instructor.

272C. Numerical Partial Differential Equations III (4)
Time dependent (parabolic and hyperbolic) PDEs. Method of lines. Stiff systems of ODEs. Space-time finite element methods. Adaptive meshing algorithms. A posteriori error estimates. **Prerequisites:** Math. 272B or consent of instructor.

273A. Advanced Techniques in Computational Mathematics I (4)
Models of physical systems, calculus of variations, principle of least action. Discretization techniques for variational problems, geometric integrators, advanced techniques in numerical discretization. Project-oriented; projects designed around problems of current interest in science, mathematics, and engineering. **Prerequisite:** graduate standing or consent of instructor.

273B. Advanced Techniques in Computational Mathematics II (4)
Nonlinear functional analysis for numerical treatment of nonlinear PDE. Numerical continuation methods, pseudo-arclength continuation, gradient flow techniques, and other advanced techniques in computational nonlinear PDE. Project-oriented; projects designed around problems of current interest in science, mathematics, and engineering. **Prerequisite:** Math. 273A or consent of instructor.

273C. Advanced Techniques in Computational Mathematics III (4)
Adaptive numerical methods for capturing all scales in one model, multiscale and multiphysics modeling frameworks, and other advanced techniques in computational multiscale/multiphysics modeling. Project-oriented; projects designed around problems of current interest in science, mathematics, and engineering. **Prerequisite:** Math. 273B or consent of instructor.

274. Numerical Methods for Physical Modeling (4)
(Conjoined with Math. 174.) Floating point arithmetic, direct and iterative solution of linear equations, iterative solution of nonlinear equations, optimization, approximation theory, interpolation, quadrature, numerical methods for initial and boundary value problems in ordinary differential equations. Students may not receive credit for both Math. 174 and PHYS 105, AMES 153 or 154. Students may not receive credit for Math. 174 if Math. 170A, B, or C has already been taken. Graduate students will complete an additional assignment/exam. **Prerequisites:** Math. 20D or 21D, and either Math. 20F or Math. 31AH, or consent of instructor.

275. Numerical Methods for Partial Differential Equations (4)
(Conjoined with Math. 175.) Mathematical background for working with partial differential equations. Survey of finite difference, finite element, and other numerical methods for the solution of elliptic, parabolic, and hyperbolic partial differential equations. Formerly Math. 172; students may not receive credit for Math. 175/275 and Math. 172. Graduate students will do an extra paper, project, or presentation, per instructor. **Prerequisite:** Math. 174 or Math. 274 or consent of instructor.

276. Numerical Analysis in Multi-Scale Biology (4)
(Cross-listed with BENG 276/CHEM 276.) Introduces mathematical tools to simulate biological processes at multiple scales. Numerical methods for ordinary and partial differential equations (deterministic and stochastic), and methods for parallel computing and visualization. Hands-on use of computers emphasized, students will apply numerical methods in individual projects. **Prerequisite:** consent of instructor.

277A. Topics in Computational and Applied Mathematics (4)
Topics vary from year to year. May be repeated for credit with consent of advisor. **Prerequisite:** graduate standing or consent of instructor.

277B. Topics in Numerical Mathematics (4)
Topics vary from year to year. May be repeated for credit with consent of advisor. **Prerequisite:** consent of instructor.

278A. Seminar in Computational Mathematics (1)
Various topics in computational mathematics. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

278B. Seminar in Mathematical Physics/PDE (1)
Various topics in mathematical physics and partial differential equations. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

279. Projects in Computational and Applied Mathematics (4)
(Conjoined with Math. 179.) Mathematical models of physical systems arising in science and engineering, good models and well-posedness, numerical and other approximation techniques, solution algorithms for linear and nonlinear approximation problems, scientific visualizations, scientific software design and engineering, project-oriented. Graduate students will do an extra paper, project, or presentation per instructor. **Prerequisite:** Math. 174 or Math. 274, or consent of instructor.

280A-B-C. Probability Theory (4-4-4)
Probability measures; Borel fields; conditional probabilities, sums of independent random variables; limit theorems; zero-one laws; stochastic processes. **Prerequisites:** advanced calculus and consent of instructor. (F,W,S)

281A. Mathematical Statistics (4)
Statistical models, sufficiency, efficiency, optimal estimation, least squares and maximum likelihood, large sample theory. **Prerequisites:** advanced calculus and basic probability theory or consent of instructor.

281B. Mathematical Statistics (4)
Hypothesis testing and confidence intervals, one-sample and two-sample problems. Bayes theory, statistical decision theory, linear models and regression. **Prerequisites:** advanced calculus and basic probability theory or consent of instructor.

281C. Mathematical Statistics (4)
Nonparametrics: tests, regression, density estimation, bootstrap and jackknife. Introduction to statistical computing using S plus. **Prerequisites:** advanced calculus and basic probability theory or consent of instructor.

282A-B. Applied Statistics (4-4)
Sequence in applied statistics. First quarter: general theory of linear models with applications to regression analysis. Second quarter: analysis of variance and covariance and experimental design. Third quarter: further topics to be selected by instructor. Emphasis throughout is on the analysis of actual data. **Prerequisite:** Math. 181B or equivalent or consent of instructor. (S/U grades permitted.)

283. Statistical Methods in Bioinformatics (4)
This course will cover material related to the analysis of modern genomic data; sequence analysis, gene expression/functional genomics analysis, and gene mapping/applied population genetics. The course will focus on statistical modeling and inference issues and not on database mining techniques. **Prerequisites:** one year of calculus, one statistics course or consent of instructor.

285. Stochastic Processes (4)
Elements of stochastic processes, Markov chains, hidden Markov models, martingales, Brownian motion, Gaussian processes. **Prerequisite:** Math. 180A (or equivalent) or consent of instructor.

286. Stochastic Differential Equations (4)
Review of continuous martingale theory. Stochastic integration for continuous semimartingales. Existence and uniqueness theory for stochastic differential equations. Strong Markov property. Selected applications. **Prerequisite:** Math. 280A-B or consent of instructor.

287A. Time Series Analysis (4)
Discussion of finite parameter schemes in the Gaussian and non-Gaussian context. Estimation for finite parameter schemes. Stationary processes and their spectral representation. Spectral estimation. **Prerequisite:** Math. 181B or equivalent or consent of instructor.

287B. Multivariate Analysis (4)
Bivariate and more general multivariate normal distribution. Study of tests based on Hotelling_s T2. Principal components, canonical correlations, and factor analysis will be discussed as well as some competing nonparametric methods, such as cluster analysis. **Prerequisite:** Math. 181B (or equivalent) or consent of instructor.

287C. Advanced Time Series Analysis (4)
Nonparametric function (spectrum, density, regression) estimation from time series data. Nonlinear time series models (threshold AR, ARCH, GARCH, etc.). Nonparametric forms of ARMA and GARCH. Multivariate time series. **Prerequisite:** Math. 287B or consent of instructor.

287D. Statistical Learning (4)
Topics include regression methods: (penalized) linear regression and kernel smoothing; classification methods: logistic regression and support vector machines; model selection; and mathematical tools and concepts useful for theoretical results such as VC dimension, concentration of measure, and empirical processes. **Prerequisite:** Math. 287C or consent of instructor.

288. Seminar in Probability and Statistics (1)
Various topics in probability and statistics. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

289A-B. Topics in Probability and Statistics (4-4)
In recent years, topics have included Markov processes, martingale theory, stochastic processes, stationary and Gaussian processes, ergodic theory. May be repeated for credit with consent of advisor.

290A-B-C. Topology (4-4-4)
Point set topology, including separation axioms, compactness, connectedness. Algebraic topology, including the fundamental group, covering spaces, homology and cohomology. Homotopy or applications to manifolds as time permits. **Prerequisites:** Math. 100A-B-C and Math. 140A-B-C. (F,W,S)

291A-B-C. Topics in Topology (4-4-4)
In recent years, topics have included generalized cohomology theory, spectral sequences, K-theory, homotophy theory. **Prerequisite:** consent of instructor.

292. Seminar in Topology (1)
Various topics in topology. **Prerequisite:** graduate standing or consent of instructor. (S/U grade only.)

294. The Mathematics of Finance (4)
Introduction to the mathematics of financial models. Hedging, pricing by arbitrage. Discrete and continuous stochastic models. Martingales. Brownian motion, stochastic calculus. Black-Scholes model, adaptations to dividend paying equities, currencies and coupon-paying bonds, interest rate market, foreign exchange models. **Prerequisite:** Math. 180A (or equivalent probability course) or consent of instructor.

295. Special Topics in Mathematics (1 to 4)
A variety of topics and current research results in mathematics will be presented by staff members and students under faculty direction.

296. Student Colloquium (1 to 2)
A variety of topics and current research in mathematics will be presented by guest lecturers and students under faculty direction. **Prerequisites:** for one unit—upper-division status or consent of instructor (may only be taken P/NP), or graduate status (may only be taken S/U); for two units—consent of instructor, standard grading option allowed.

297. Mathematics Graduate Research Internship (2–4)
An enrichment program which provides work experience with public/private sector employers and researchers. Under supervision of a faculty advisor, students provide mathematical consultation services. **Prerequisites:** consent of instructor.

299. Reading and Research (1 to 12)
Independent study and research for the doctoral dissertation. One to three credits will be given for independent study (reading) and one to nine for research. **Prerequisite:** consent of instructor. (S/U grades permitted.)

TEACHING OF MATHEMATICS

500. Apprentice Teaching (1 to 4)
Supervised teaching as part of the mathematics instructional program on campus (or, in special cases such as the CTF program, off campus). **Prerequisite:** consent of advisor. (S/U grades only.)

501. Seminar in Teaching Development (1)
A seminar designed for graduate students serving as teaching assistants in mathematics. Includes discussion of teaching theories, techniques, and materials with a focus on career development. **Prerequisite:** graduate standing or consent of instructor. (S/U grades only.)