Mathematics

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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 seven majors leading to the B.A. degree: mathematics, applied mathematics, applied mathematics-scientific programming, mathematics-computer science, mathematics-secondary education, and a joint major in mathematics and economics. In addition, students can minor in mathematics. The department also has an Honors Program for exceptional students in any of the seven 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 that are offered by the department. You may visit our Web site, 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 prior to orientation unless they have, or will have, either a passing score (3 or better) on a Calculus AP exam, or transferable credit in calculus. The purpose of the placement exam is to assess the student's readiness to enter the department's calculus courses. Some students will be required to take precalculus courses before beginning a calculus sequence.

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-D (formerly numbered 1A-B-C) is one of two 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 other first-year calculus sequence, Math. 20A-B/21C, 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-D 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. 21D/20E-F which is required for some science and engineering majors. **Note:** As of winter 2000, Math. 20C and 20D are no longer offered and have been replaced with Math. 21C and 21D.

Certain transfers between the Math. 10 and Math. 20 sequences are possible, but such transfers should be carefully discussed with an adviser. 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. This option is available only if the student obtains a grade of A in Math. 10A or by consent of the Math. 20A instructor.
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. 21C.

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

Major Programs

The department offers seven different majors leading to the Bachelor of Arts degree: (1) mathematics, (2) applied mathematics, (3) applied mathematics (scientific programming), (4) mathematics-computer science, (5) mathematics-applied science, (6) mathematics-secondary education and (7) joint major in mathematics and economics. 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, 198, and 199 cannot be used towards any mathematics major.) All courses used to fulfill the major must be taken for a letter grade.

It is strongly recommended that all mathematics majors review their programs at least annually with a departmental adviser, and that they consult with the Advising Office in AP&M 2313 before making any changes to their programs. The department holds a quarterly meeting for majors where general information is discussed. Current course offering information for the entire year is maintained on the department's web page at http://math.ucsd.edu. Special announcements are also emailed to all majors.

Students who plan to go on to graduate school 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 year of abstract algebra as well as a full year of analysis. 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.

Education Abroad

Students may be able to participate in the UC Education Abroad Program (EAP) and UCSD'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 *UCSD General Catalog* and the Web site http://orpheus.ucsd.edu/icenter/pao.

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.

All students majoring in mathematics must complete the basic 20 sequence. Math. 109 should be taken in the spring quarter of the sophomore year. All mathematics majors must complete at least twelve upper-division courses including:

1. 109
2. 140A-B
3. 100A-B or 103A-B

Upper-division electives to complete the twelve courses required may be chosen from any mathematics course numbered 100–194.

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

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 (103A-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.

All students majoring in applied mathematics are required to complete the following courses:

1. Calculus: 20A-B, 21C-D, 20E-F
2. Mathematical Reasoning: 109 (should be taken in sophomore year)
3. Programming:
   MAE 9 (C++) or MAE 10 (Fortran) or
   CSE 8AB (Java) or CSE 11 (Java)
4. Linear Algebra: Math. 102 or 170A.
5. Statistics: 183 or 181A. See section on duplication of credit.
6. Advanced Calculus: Math. 142A-B (or 140A-B). (Math. 142A-B should be taken during the junior year).
7. One of the following sequences: 180A-B-C (probability), 180A–181A-B* (probability and statistics), or any three courses from 170A-B-C, 172, and 173 (numerical analysis). [*Math. 181C, D or E may be substituted for 181B.] See section on duplication of credit.
8. One additional sequence which may be chosen from the list (#7) above or the following list: 110-120A-130A, 120A-B, 130A-132A, 155A-B, 171A-B, 184A-B, 193A-B.

At least thirteen upper-division courses must be completed in mathematics, except:

a. Up to twelve units may be outside the department in an approved applied mathematical area. A petition specifying the courses to be used must be approved by an applied mathematics adviser. No such units may also be used for a minor or program of concentration.
b. MAE 154, Econ. 120A-B-C, cannot be counted toward the fifty-two units.

To be prepared for a strong major curriculum, students should complete the last three quarters of the 20 sequence (Math. 21D, 20E-F) and Math. 109 before the end of their sophomore year.

Major in Applied Mathematics (Scientific Programming)

This is a specialized applied mathematics program with a concentration in scientific programming, i.e., computer solution of scientific problems. The requirements are those of the applied mathematics major, except for the following additions and substitutions:

1. Physics 1A-B-C, or 2A-B-C, or 4A-B-C
2. Instead of items 7 and 8 in the applied mathematics major, the following courses are required:
   (7) any three from 170A-B-C, 172, 173
   (8) 171A-B

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:

1. Math. 20A-B, 21C-D, 20E-F
   One of the following is recommended
   CSE 8A-B Intro to Computer Sci: Java
   CSE 11 Intro to Computer Sci: Java (Accelerated Pace)
   MAE 9 C/C++ Programming
   MAE 10 FORTRAN for Engineers
2. Seven upper-division mathematics courses that include:
   a) Math. 109
   and
   b) Math. 102 or Math. 170A
   and
   c) Any two-quarter upper-division math sequence.

Applied Science Requirement:

1. Seven upper-division courses selected from one or two other departments
2. At least three of these seven upper-division courses must require at least Math. 21C as a prerequisite

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

Major in Mathematics–Computer Science

The program provides for a major in computer science within the Department of Mathematics. 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.

The curriculum for the B.A. in mathematics-computer science requires thirty-six units of lower-division courses and fifty-six units of upper-division courses.

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 following list.

Lower-Division Requirements:

1. Calculus: Math. 20A-B, 21C-D, 20E-F
2. Intro to Computer Science—CSE 8A-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

Upper-Division Requirements:

5. Mathematical Reasoning: Math. 109
6. Modern Applied Algebra: Math. 103AB (or Modern Algebra: Math. 100AB)
7. Theory of Computability: Math. 166
8. Intro to Probability: Math. 180A
9. Mathematical Foundations of Computer Science: Math. 184A
10. Computer Implementations of Data Structures: Math. 176 or Data Structures: CSE 100
11. Design & Analysis of Algorithms: CSE 101
12. Eight units from: Math. 170A, B, C, 172, 173, 174
13. Eight units from: Math. 107A-B, 155A-B, 160A-B, 166B, 168A-B, 179A-B, 184B, 187, CSE 120-121, 130, 131A-B, 140-140L, 141-141L
14. Eight additional units from: any course in list 12 or 13 above or Math. 102, 110, 111A-B, 130A-B, 131, 132A-B, 140A-B, 181A-B-C

In order to graduate by the end of their senior year, students must complete Math. 103A-B by the end of their junior year.

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 mathematics major and the economics/management science majors.

Lower-Division Requirements:

1. Calculus: Math. 20A-B, 21C-D, 20F
2. Intro to Economics: Econ. 1A or 2A, and 1B or 2B

Upper-Division Requirements:

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):

1. Mathematical Reasoning: Math. 109

2. One of the following:
   Applied Linear Algebra: Math. 102
   Numerical Linear Algebra: Math. 170A
   Modern Algebra: Math. 100AB
3. One of the following:
   Foundations of Analysis: Math. 140A
   Advanced Calculus: Math. 142A
4. One of the following:
   Ordinary Differential Equations: Math. 130A,
   Foundations of Analysis: Math. 140B
   Advanced Calculus: Math. 142B
5. One of the following:
   Microeconomics: Econ. 100A-B
   Management Science Microeconomics:
     Econ. 170AB
6. Econometrics: Econ. 120A-B-C or
     Math. 180A and Econ. 120B-C
   or
   Probability: Math. 180A, 181A and Econ. 120C
7. One of the following:
   Macroeconomics: Econ. 110AB
   Mathematical Programming: Numerical
     Optimization: Math. 171AB
   or
   Two courses from the following:
   Decisions Under Uncertainty: Econ. 171
   Introduction to Operations Research:
     Econ. 172A-B-C, (**Note**: 172A is a
     prerequisite for 172BC)

Other courses which are strongly recommended are: Math. 130B, 131, 181B, 190 and 193AB and Econ. 109, 113, 155, 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 Teacher Education Program (TEP) for information regarding prerequisites and requirements. It is recommended you contact TEP as early as possible.

Lower-Division Requirements

1. Calculus 20A-B, 21C-D, 20E-F

Recommended:

1. One of the following:
   Introduction to Computer Science:
     Java: CSE 8A-B,
     Fortran: MAE 10
     C/C++ Programming: MAE 9

Upper-Division Requirements:

1. Mathematical Reasoning: Math. 109
2. Number Theory: Math 104A
3. History of Mathematics: Math. 163
4. Practicum in Learning: TEP 129A-B-C
5. One of the following:
   Computer Algebra: Math. 107A
   Computer Graphics: Math. 155A
   Numerical Linear Algebra: Math. 170A
   Intro. to Cryptography: Math. 187
   Mathematical Computing: Math. 161
6. One of the following:
   Intro. to Probability: Math. 180A
   Statistical Methods: Math. 183
7. One of the following:
   Differential Geometry: Math. 150A
   Topics in Geometry: Math 151
   Intro. to Topology: Math. 190
8. One of the Following:
   Modern Algebra: Math. 100A
   Applied Linear Algebra: Math. 102
   Modern Applied Algebra: Math. 103A
9. One of the following:
   Foundations of Analysis: Math. 140A
   Advanced Calculus: Math. 142A
10. Upper-division courses must total twelve upper-division courses chosen from items 2–10. Upper-division courses must include at least one two-quarter sequence from the following list:

    100A-B; 103A-B, 103A-102; 104A-B; 110-120A; 110-130A-B; 110-132A; 110-131; 117-190; 120A-B; 130A-132A; 130A-B; 140A-B; 141-190; 142A-B; 150A-B; 155A-B; 160A-B; 170A-B; 170A-172; 170A-173; 170A-171A; 171A-B; 180A-B; 180A-181A; 184A-B; 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. 21D, 20E, and 20F.

Math. 195, 196, 198, and 199 are not acceptable courses for the mathematics minor. A grade of C– or better (or P if the Pass/No 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.

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

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) and at least one of Math. 100A, 103A, 140A, or 142A. (Completion of additional major courses is strongly recommended.)

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 seupervision of a faculty adviser. 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 2313). Completed applications can be returned to the Mathematics Advising Office.

Duplication of Credit

In the circumstances listed below, a student will not receive full credit for a Department of Mathematics course. The notation "Math. 20A [2 if Math. 10A previously/0 if Math. 10A concurrently/0 if Math. 10B or 10C]" means that a student already having credit for Math. 10A will receive only two units of credit for Math. 20A, but will receive no units if he or she has credit for Math. 10B or 10C, and no credit will be awarded for Math. 20A if Math. 10A is being taken concurrently. Math. 4C cannot be taken for credit after Math. 10 or Math. 20.

1. Math. 15A [0 if CSE20]
   Math. 15B [0 if CSE21]
2. Math. 20A [2 if Math. 10A previously/0 if Math. 10A concurrently/0 if Math. 10B or 10C]
3. Math. 20B [2 if Math. 10B or 10C previous ly/0 if Math. 10B concurrently]
4. Math. 21C [2 if Math. 10C previously/0 if Math. 10C concurrently]
5. Math. 21D [2 if Math. 20D previously/0 if Math. 2DA previously]
6. Math. 20E [0 if Math. 2F previously]
7. Math. 20F [0 if Math. 2EA previously]
8. Both Math. 100 and Math. 103 cannot be taken for credit
9. Math. 142A-B [0 if Math. 140A-B]
10. Math. 155A [0 if CSE 167]
11. Math. 166 [0 if CSE105]
12. Math. 174 [0 if 170A or B or C previously]
13. Math. 180A [2 if Econ. 120A or Math. 183 previously/0 if Econ. 120A or Math. 183 concurrently]
14. Math. 181A [2 if Econ. 120B/0 if Econ. 120B concurrently]
15. Math. 183 [0 if Econ. 120A, 2 if Math. 180A previously and 0 if Math. 180A or Econ. 120A concurrently]

For duplication or repeat of credit guidelines between the Math. 20 sequence and the Math. 10 sequence, refer to the section titled "First-Year Courses."

Advisers

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

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 15. 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 adviser 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 adviser.

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 adviser.

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

a. No more than eight units of upper-division mathematics courses.

b. No more than twelve units of graduate courses in a related field outside the department (approved by the Department of Mathematics).

c. No more than four units of Math. 295 (Special Topics) or Math. 500 (Apprentice Teaching).

d. 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.	(Combinatorial 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.	(Scientific Computation)

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:

a. 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];

b. A maximum of eight units can be approved upper-division courses in mathematics; and

c. A maximum of eight units can be approved upper-division courses in other departments.

d. A maximum of four units of Math. 500 (Apprentice Teaching).

e. 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 adviser 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-four units, including:

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

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

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

a. For a theoretical emphasis, Math. 280A-B-C (Probability Theory) is required.

b. For an applied orientation, Math. 270A-B-C (Numerical Mathematics) is recommended.

c. A maximum of eight units of approved upper-division applied mathematics courses (see faculty adviser) and Math. 500 (Apprentice Teaching).

Upon the approval of the faculty adviser, all twenty-four units can be graduate-level courses in other departments.

COMPREHENSIVE EXAMINATIONS

Two written comprehensive examinations must be passed at the master's level in related course work (approved by a faculty adviser). 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)

i) 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.

ii) 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.

iii) 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.)

iv) 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 a 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 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 adviser is found. Approval by the Qualifying Exam and Appeals Committee (QEAC) is not automatic, however.

Exams are typically offered twice a year, one scheduled late 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 adviser and take a broad selection of courses including applied mathematics, such as those in Area #3.

FOREIGN LANGUAGE REQUIREMENT

A reading knowledge of two foreign languages (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 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.

COURSES

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 logarithm, 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. C, 1A/10A, or 2A/20A.) *Prerequisite: two or more years of high school mathematics or equivalent.*

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: qualifying score on placement examination. With a superior performance in Math. 3C, the placement examination requirement may be waived.*

10A. Calculus (4)
Differentiation and integration of algebraic functions. Fundamental theorem of calculus. Applications. (No credit given if taken after Math. 2A/20A. Formerly numbered Math. 1A.) *Prerequisite: qualifying score on placement examination. With a passing grade in Math. 3C, the placement examination requirement may be waived.*

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: Math. 1A or 10A.*

10C. Calculus (4)
Vector geometry, velocity, and acceleration vectors. (No credit given if taken after Math. 2C/20C. Formerly numbered Math. 1C.) *Prerequisite: Math. 1B or 10B.*

10D. Elementary Probability and Statistics (4)
Events and probabilities, combinatorics, conditional probability, Bayes formula. Discrete random variables: mean, variance; binomial, multinomial, Poisson distributions. Continuous random variables: densities, mean, variance; normal, uniform, exponential distributions. Sample statistics, confidence intervals, regression. Applications. Intended for biology and social science majors. *Prerequisites: Math. 10A-B or Math. 20A-B.*

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. *Prerequisites: CSE 8A & 9B or 10 or 8A & 8B or 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. *Prerequisite: Math. 15A or CSE 20 or 160A; CSE 12 is strongly recommended for CSE 21.*

17. Geometry and the Imagination (4)
Down-to-earth approach to deep mathematical ideas, emphasizing the richness, diversity, connectedness, and pleasure of mathematics. Assignments emphasize thinking and writing. Discussions and projects replace traditional lectures and exams. Accessible to enthusiastic students of widely varying backgrounds. Topics: see Math. 117. *Prerequisite: calculus occasionally helpful but not necessary.*

18. Computer Animated Statistics (4)
Students will acquire the basics of statistical analysis by working with computer-simulated models rather than abstract mathematical language. Topics include hypothesis testing, maximum likelihood estimation, sampling, chi-square tests and construction of confidence intervals. *Prerequisite: Math. 1B or 10B or 20B.*

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: qualifying score on placement examination or completion of Math. 4C with a grade of B 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. Polar coordinates in the plane. (Two units of credits given if taken after Math. 1B/10B or Math. 1C/10C.) *Prerequisite: Math. 20A or equivalent / Score of 4 or better on AB calculus AP test.*

20BL. Honors Mathematics Laboratory (2)
Symbolic, numerical, and graphical explorations of the material of Math. 20B. Student should have received a grade of A– or better in Math. 20A (or equivalent course). *Prerequisite: Math. 20A with corequisite of Math. 20B or consent of instructor.* (W)

20CL. Honors Mathematics Laboratory (2)
Symbolic, numerical, and graphical explorations of the material of Math. 20C/21C. Student should have received a grade of A– or better in Math. 20B (or equivalent course). *Prerequisite: Math. 20B with corequisite of Math. 20C/21C or consent of instructor.* (S)

20E. Vector Calculus (4)
Change of variable in multiple integrals, Jacobian Line integrals, Green's theorem. Vector fields, gradient fields, divergence, curl. Spherical and cylindrical coordinates. Taylor series in several variables. Surface integrals, Stoke's theorem. Gauss' theorem and its applications. Conservative fields. (Zero units given if Math. 2F previously. Formerly numbered Math. 2F) *Prerequisite: Math. 21C (or 20C) or equivalent, or consent of instructor.*

20F. Linear Algebra (4)
Matrix algebra, solution of systems of linear equations by 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. (Zero units given if Math. 2EA previously. Formerly numbered 2EA.) *Prerequisite: Math. 21C (or 20C) or equivalent or consent of instructor.*

21C. 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 credits given if taken after Math. 1C/10C. Formerly numbered Math. 2C.) *Prerequisite: Math. 2B/20B or equivalent or consent of instructor.*

21D. Introduction to Differential Equations (4)
Infinite series. Ordinary differential equations: exact, separable, and linear; constant coefficients, undetermined coefficients, variation of parameters. Series solutions. Systems, Laplace transforms. Techniques for engineering sciences. Computing symbolic and graphical solutions using Matlab. (Two units if Math. 20D previously, zero if Math. 2DA previously. Formerly numbered Math. 2DA.) *Prerequisite: Math. 21C or equivalent.*

69. Chance (4)
Explores role chance plays in our world; introduces basic tools of probability theory that are used to build, analyze, and interpret mathematical models of chance phenomena. Math. 169 is the enhanced version of Math. 69 for math majors, requiring one additional lecture per week, more advanced topics, and more difficult assignments. Four lectures, one recitation. *Prerequisite: Math. 20C or 21C, or a grade of A– or better in Math. 20B, or consent of instructor.*

93. Theory of Interest (4)
Interest, annuities, amortization, sinking funds, bonds, and other securities. Preparation for actuarial exam 140. *Prerequisite: Math. 10C or Math. 20B.*

UPPER-DIVISION

100A-B-C. Modern Algebra (4-4-4)
An introduction to the methods and basic structures of higher algebra: sets and mappings, the integers, rational, real and complex numbers, groups, rings (especially polynomial rings) and ideals, fields, real and complex vector spaces, linear transformations, inner product spaces, matrices, triangular form, diagonalization. Both 100 and 103 cannot be taken for credit. Three lectures, one recitation. *Prerequisites: Math. 20F, and Math. 109 or consent of instructor.* (F,W,S)

102. Applied Linear Algebra (4)
A 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. Three lectures, one recitation. *Prerequisite: Math. 20F.* (W)

103A-B. Modern Applied Algebra (4-4)
Abstract algebra with applications to computation. Set algebra and graph theory. Finite state machines. Boolean algebras and switching theory. Lattices. Groups, rings and fields: applications to coding theory. Recurrent sequences. Three lectures, one recitation. Both 100 and 103 cannot be taken for credit. *Prerequisites: Math. 20F and Math. 109 (may be taken concurrently).* (F,W)

104A-B-C. Number Theory (4-4-4)
Topics from number theory with applications and computing. Possible topics are: congruences, reciprocity laws, quadratic forms, prime number theorem, Riemann zeta function, Fermat's conjecture, diophantine equations, Gaussian sums, algebraic integers, unique factorization into prime ideals in algebraic number fields, class number, units, splitting of prime ideals in extensions, quadratic and cyclotomic fields, partitions. Possible applications are Fast Fourier Transform, signal processing, coding, cryptography. Three lectures. *Prerequisite: consent of instructor.*

107A-B. Computer Algebra (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. *Prere-quisite: prior or concurrent enrollment in the Math. 100 or 103 sequence.*

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.*

110. 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. *Prerequisites: Math. 20D (or 21D) and 20F, or consent of instructor.* (F,S)

111A-B. Mathematical Model Building (4-4)
Analytic techniques and simulation methods will be used to study a variety of models. Students will work on independent projects. Three lectures. *Prerequisites: Math. 20D (21D) and 20F.*

117. Geometry and the Imagination for Math Majors (4)
Enhanced Math. 17 for advanced mathematics students. Topics: Geometry and topology in dimensions 2, 3, and higher; polyhedra; Euler characteristic; hyperbolic geometry; knots; symmetry; orbifolds; the 17 kinds of wall paper; curvature; soap films; telling cabbage from kale; Gauss-Bonnet theorem. *Prerequisite: Math. 20C/21C or equivalent.*

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. Three lectures, one recitation. *Prerequisite or co-registration: Math. 20E, 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 problem. Neumann's problem, or special functions. Three lectures, one recitation. *Prerequisite: Math. 120A.* (W,S)

130A. Ordinary Differential Equations (4)
Linear and nonlinear systems of differential equations. Stability theory, perturbation theory. Applications and introduction to numerical solutions. Three lectures. *Prerequisites: Math. 20D/21D and 20F.* (F)

130B. Ordinary Differential Equations (4)
Existence and uniqueness of solutions to differential equations. Local and global theorems of continuity and differentiabillity. Three lectures. *Prerequisites: Math. 20D/21D and 20F, and Math. 130A.* (W)

131. Variational Methods in Optimization (4)
Maximum-minimum problems. Normed vector spaces, functionals, Gateaux variations. Euler-Lagrange multiplier theorem for an extremum with constraints. Calculus of variations via the multiplier theorem. Applications may be taken from a variety of areas such as the following: applied mechanics, elasticity, economics, production planning and resource allocation, astronautics, rocket control, physics, Fermat's principle and Hamilton's principle, geometry, geodesic curves, control theory, elementary bang-bang problems. Three lectures, one recitation. *Prerequisites: Math. 20D/21D and 20F or consent of instructor.* (S)

132A. 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. Three lectures. *Prerequisite: Math. 110 or consent of instructor.* (W)

132B. Elements of Partial Differential Equations and Integral Equations (4)
Relation between differential and integral equations, some classical integral equations, Volterra integral equations, integral equations of the second kind, degenerate kernels, Fredholm alternative, Neumann-Liouville series, the resolvent kernel. Three lectures. *Prerequisite: Math. 132A.* (S)

140A-B-C. Foundations of Analysis (4-4-4)
Axioms, the real number system, topology of the real line, metric spaces, continuous functions, sequences of functions, differentiation, Riemann-Stieltjes integration, partial differentiation, multiple integration, Jacobians. Additional topics at the discretion of the instructor: power series, Fourier series, successive approximations of other infinite processes. Three lectures, one recita-

tion. *Prerequisites: Math. 20E and Math. 109 or consent of instructor.* Credit cannot be obtained for both Math. 140A-B and 142A-B. (F,W,S)

141. Introduction to Abstract Analysis (4)
General topological spaces, compactness, separation, locally compact Hausdorff spaces, metrization, completeness, Baire category, Stone-Weierstrass theorem, function spaces. Three lectures. *Prerequisites: Math. 140A-B or equivalent.* (F)

142A-B. Advanced Calculus (4-4)
The number system. Functions, sequences, and limits. Continuity and differentiability. The Riemann integral. Transcendental functions. Limits and continuity. Infinite series. Sequences and series of functions. Uniform convergence. Taylor series. Improper integrals. Gamma and Beta functions. Fourier series. Three lectures. *Prerequisite: Math. 20E.* Credit cannot be obtained for both Math. 140A-B and 142A-B.

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

150B-C. Calculus on Manifolds (4-4)
Calculus of functions of several variables, inverse function theorem. Further topics, selected by instructor, such as 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. Three lectures. *Prerequisite: Math. 150A.* (W)

151. Topics in Geometry (4)
A topic, selected by the instructor, from Euclidean geometry, non-Euclidean geometry, projective geometry, algebraic geometry, or other geometries. May be repeated for credit with a different topic. Three lectures. *Prerequisite: consent of instructor.* (S)

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 or 21D, and 20F 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. Three lectures, one recitation, and approximately eight laboratory hours per week. *Prerequisites: Math. 20F and programming experience.* [Warning: There are duplicate credit restrictions on this course. See section on Duplication of Credit.] (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. Three lectures, one recitation, and approximately eight laboratory hours per week. *Prerequisite: Math. 155A or consent of instructor.* (W)

155C. Topics in Computer Graphics (4)
Tensor product and Bezier patch surfaces, perspective transformations, projective cross ratios, elevation of degree, derivatives across edges, calculation of illumination intensity. Three lectures, one recitation, and approximately eight laboratory hours per week. *Prerequisite: Math. 155B or consent of instructor.* (S)

160A-B. Elementary Mathematical Logic (4-4)
An introduction to recursion theory, set theory, proof theory, and model theory. Turing machines. Undecidability of arithmetic and predicate logic. Proof by induction and definition by recursion. Cardinal and ordinal numbers. Completeness and compactness theorems for propositional and predicate calculi. Three lectures. *Prerequisite: Math. 100A, 103A, 140A, or consent of instructor.*

161. Mathematical Computing (2 or 4)
Programming in higher level mathematical language such as Mathematica: Lists, Functions, Expressions, Recursion, Iteration, graphics, packages. Application to diverse areas of mathematics such as differential equations, dynamical systems, fractals, chaos, probability, financial models. *Prerequisite: Math. 20A-B, 21C-D, 20E-F or equivalent.*

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)

165. Introduction to Set Theory (4)
Sets, relations, and functions. Partial, linear, and well-orders. The axiom of choice, proof by induction and definition by recursion. Cardinal and ordinal numbers and their arithmetic. *Prerequisite: Math. 100A or 140A or 103, or consent of instructor.*

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.*

168A-B. Topics in Applied Mathematics-Computer Science (4-4)
Topics to be chosen in areas of applied mathematics and mathematical aspects of computer science. May be repeated once for credit with different topics. Three lectures, one recitation. *Prerequisite: consent of instructor.* (W,S)

169. Chance (4)
Math 69 explores role chance plays in our world; introduces basic tools of probability theory that are used to build, analyze, and interpret mathematical models of chance phenomena. Math 169 is the enhanced version of Math 69 for math majors, requiring one additional lecture per week, more advanced topics and more difficult assignments. Four lectures, one recitation. *Prerequisite: Math 20F.*

170A. Numerical 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. *Prerequisites: Math. 20F and knowledge of programming.* (F,S)

170B. Numerical Analysis (4)
Rounding and discretization errors. Calculation of roots of polynomials and nonlinear equations. Interpolation. Approximation of functions. Three lectures, one recitation. *Prerequisites: Math. 20F and knowledge of programming.* (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-B. Mathematical Programming–Numerical Optimization (4-4)
Mathematical optimization and applications. Linear programming, the simplex method, duality. Nonlinear programming, Kuhn-Tucker theorem. Selected topics from integer programming, network flows, transportation problems, inventory problems, and other applications. Three lectures, one recitation. *Prerequisites: Math. 20F and knowledge of programming.*

172. Numerical Partial Differential Equations (4)
Finite difference methods for the numerical solution of hyperbolic and parabolic partial differential equations; finite difference and finite element methods for elliptic partial differential equations. Three lectures. *Prerequisites: Math. 170A or Math. 110 and programming experience.* (F)

173. Mathematical Software–Scientific Programming (4)
Development of high quality mathematical software for the computer solution of mathematical problems. Three lectures, one recitation. *Prerequisites: Math. 170A or Math. 174 and knowledge of FORTRAN.* (W)

174. Numerical Methods in Science and Engineering (4)
Floating point arithmetic, linear equations, interpolation, integration, differential equations, nonlinear equations, optimization, least squares. Students may not receive credit for both Math. 174 and Physics 105 or MAE 153 or 154. Students may not receive credit for Math. 174 if Math. 170 A,B, or C has already been taken. *Prerequisites: Math. 21D (2DA) and Math. 20F (2EA).*

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. Crecit 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.*

179A-B. Introduction to Artificial Intelligence (4-4)
An introduction to artificial intelligence through its mathematics. The course will develop various areas of mathematics, including logic, probability and optimization. These tools will be applied to various areas of artificial intelligence, including deductive reasoning, uncertain reasoning, neural networks and search. One

of the programming languages Prolog and Lisp will be introduced and used for course work. *Prerequisite: Math. 109, 100A or 103A (100A or 103A may be taken concurrently).* (W,S)

180A. Introduction to Probability (4)
Probability spaces, random variables, independence, conditional probability, distribution, expectation, joint distributions, central-limit theorem. Three lectures. *Prerequisites: Math. 20D/21D.* [Warning: There are duplicate credit restrictions on this course. See section on Duplication of Credit.] (F)

180B. Introduction to Probability (4)
Random vectors, multivariate densities, covariance matrix, multivariate normal distribution. Random walk, Poisson process. Other topics if time permits. Three lectures. *Prerequisites: Math. 180A and Math. 20E.* (W)

180C. Introduction to Probability (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.* (S)

181A. Introduction to Mathematical Statistics (4)
Random samples, linear regression, least squares, testing hypotheses, and estimation. Neyman-Pearson lemma, likelihood ratios. Three lectures, one recitation. *Prerequisites: Math. 180A and 20F.* [Warning: There are duplicate credit restrictions on this course. See section on Duplication of Credit.] (W)

181B. Introduction to Mathematical Statistics (4)
Goodness of fit, special small sample distribution and use, nonparametric methods. Kolmogorov-Smirnov statistics, sequential analysis. Three lectures. *Prerequisite: Math. 181A.* (S)

181C. Mathematical Statistics (4)
Nonparametric Statistics. 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. *Prerequisites: Math. 181A, 181B previously or concurrently.*

181D. Mathematical Statistics (4)
Sampling Theory. Basic notions of estimation: bias, variance, and sampling errors. Sampling from finite populations: simple random, stratified, cluster, sampling with unequal probabilities. Ratio and regression estimaters, multistage sampling. *Prerequisites: Math. 181A, 181B previously or concurrently.*

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

182. Introduction to Combinatorics (4)
Combinatorial methods and their computer implementation. Permutations and combinations, generating functions, partitions, principle of inclusion and exclusion. Polya's theory of counting. Hall's theorem, assignment problem, backtrack technique, error-correcting codes, combinatorial optimization problems. Three lectures, one recitation. *Prerequisites: Math. 20F and programming experience.* (W)

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 both Math. 183 and Econ. 120A.) *Prerequisite: Math. 21C.* (F,S)

184A-B. Mathematical Foundations of Computer Science (4-4)
Enumeration of combinatorial structures. Ranking and unranking. Graph theory with applications and algorithms. Recursive algorithms. Circuit design. Inclusion-exclusion. Generating functions. Polya theory. Three lectures, one recitation. *Prerequisite: Math. 100A or Math. 103A.* (W,S)

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.*

189A-B. Compilers (4-4)
Compilers for high-level programming languages. Project to develop a working compiler. Part A: regular expressions and finite automata, context free grammars, parsing techniques. Part B: syntax directed translation, semantic actions (for declarations, statement structures, assignments, array references, expression evaluation, procedure and function calls), symbol tables, run-time storage management. Part C: error recovery, optimization, code generation. Three lectures. *Prerequisites: Math. 166A, 176A, and 103A or consent of instructor.* (F,W,S)

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 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)

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

193B. Actuarial Mathematics (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.*

193C. Actuarial Mathematics (4)
Topics to be selected from pension plans, collective risk models, advanced topics in insurance. *Prerequisite: Math. 193B.*

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, Math. 20F, and Math. 180A or 183.*

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 (1-2)
A variety of topics and current research results in mathematics will be presented by guest lecturers and students under faculty direction. *Prerequisites: upper-division status or consent of instructor (for one unit) and consent of instructor (for two units).*

198. Directed Group Studies in Mathematics (1 to 4)
Group study course in some topic not covered in the undergraduate curriculum. (P/NP grades only.) *Prerequisite: consent of instructor.* (F,W,S)

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-C. Basic Topics in Algebra (4-4-4)
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-B-C. Applied Algebra (4-4-4)
Algebra from a computational perspective using Maple, Mathematica and Matlab. 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: 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. Topics in Algebra (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 adviser. *Prerequisite: consent of instructor.*

208. Seminar in Algebra (1-4)
Prerequisite: consent of instructor. (S/U grades permitted.)

209. Seminar in Number Theory (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

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)

211. Fourier Analysis on Finite Groups (4)
Applied group representations. Emphasis on the integers, mod n, finite matrix groups. Applications may include: the fast Fourier tranform, digital signal processing, finite difference equations, spectral graph theory, error-correcting codes, vibrating systems, finite wavelet tranforms. *Prerequisite: none.*

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 adviser. *Prerequisite: consent of instructor.*

218. Seminar in Applied Mathematics (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

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-C. Topics in Several Complex Variables (4-4-4)
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.*

227A-B-C. Topics in Complex Analysis (4-4-4)
In recent years, topics have included conformal mapping, Riemann surfaces, value distribution theory, external length. May be repeated for credit with consent of adviser. *Prerequisite: consent of instructor.*

229. Computing Technology for Mathematics (2)
Preparation for making effective use of computer technology in research and teaching of mathematics. UNIX basics, document preparation using TEX, Internet resources, HTML, computer technology in teaching. *Prerequisite: graduate status in mathematics.*

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.*

233. Singular Perturbation Theory for Differential Equations (4)
Multivariable techniques, matching techniques and averaging techniques, including various approaches to proofs of asymptotic correctness, for singular perturbation problems including initial value problems with nonuniformities at infinity, initial value problems with initial nonuniformities, two point boundary value problems, and problems for partial differential equations. Applications taken from celestial mechanics, oscillation problems, fluid dynamics, elasticity, and applied mechanics. *Prerequisites: Math. 130A-B or 132A-B or consent of instructor.* (S/U grades permitted.) (S)

237A-B. Topics in Differential Equations (4-4)
May be repeated for credit with consent of adviser. *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-C. Functional Analysis (4-4-4)
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.* (F,W,S)

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

248. Seminar in Real Analysis (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

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 (2 to 4)
Various topics in Lie groups and Lie algebras, including structure theory, representation theory, and applications. *Prerequisite: consent of instructor.* (F,W,S)

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

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-B-C. Mathematical Logic (4-4-4)
Propositional calculus and quantification theory. Completeness theorem, theory of equality, compactness theorem, Skolem-Lowenheim theorems. Vaught's test: Craig's lemma. Elementary number theory and recursive function theory. Undecidability of true arithmetic and of Peano's axioms. Church's thesis; set theory; Zermelo-Frankel axiomatic formulation. Cardinal and ordinal numbers. The axiom of choice and the generalized continuum hypothesis. Incompleteness and undecidability of set theory. Relative consistency proofs. *Prerequisites: Math. 100A-B-C or consent of instructor.*

261A-B. Combinatorial Algorithms (4-4)
Lexicographic order, backtracking, ranking algorithms, isomorph rejection, sorting, orderly algorithms, network flows and related topics, constructive Polya theory, inclusion-exclusion and seiving methods, Mobius inversion, generating functions, algorithmic graph theory, trees, recursion, depth firstsearch and applications, matroids. *Prerequisites: CSE 160A-B or Math.184A-B or consent of instructor.* (F,W,S)

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.*

263. History of Mathematics (4)
Mathematics in the nineteenth century from the original sources. Foundations of analysis and commutative algebra. For algebra the authors studied will be Lagrange, Ruffini, Gauss, Abel, Galois, Dirichlet, Kummer, Kronecker, Dedekind, Weber, M. Noether, Hilbert, Steinitz, Artin, E. Noether. For analysis they will be Cauchy, Fourier, Bolzano, Dirichlet, Riemann, Weierstrass, Heine, Cantor, Peano, Hilbert. *Prerequisites: Math. 100A-B, Math. 140A-B.*(S)

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)

267A-B-C. Topics in Mathematical Logic (4-4-4)
Topics chosen from recursion theory, model theory, and set theory. May be repeated with consent of adviser. *Prerequisite: consent of instructor.* (S/U grades permitted.)

268. Seminar in Logic (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

269. Seminar in Combinatorics (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

270A-B-C. Numerical Mathematics (4-4-4)
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. Error analysis of numerical quadrature and of the numerical solution of ordinary differential equations. *Prerequisites: Math. 20F and knowledge of programming.*

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-B-C. Numerical Partial Differential Equations (4-4-4)
The numerical solution of elliptic, parabolic, and hyperbolic partial differential equations; discretization and solution techniques. *Prerequisite: consent of instructor.* (F,W,S)

273A-B-C. Scientific Computation (4-4-4)
Continuum mechanics models of physical and biological systems, finite element methods and approximation theory, complexity of iterative methods for linear and nonlinear equations, continuation methods, adaptive methods, parallel computing, and scientific visualization. Project-oriented; theoretical and software development projects designed around problems of current interest in science and engineering. *Prerequisite: experience with Matlab and C, some background in numerical analysis, or consent of instructor.* (F,W,S)

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

278. Seminar in Numerical Mathematics (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

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. *Prere-quisites: advanced calculus and consent of instructor.* (F,W,S)

281A-B. Mathematical Statistics (4-4)
Testing and estimation, sufficiency; regression analysis; sequential analysis; statistical decision theory; nonparametric inference. *Prerequisites: advanced calculus and 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.*

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. Nonparametric Analysis (4)
Topics covered will include the Mann-Whitney and Wilcoxon, sign, median, and Kruskal-Wallis tests; permutation methods in general; tests for goodness of fit, especially those based on chi-square and Kolmogorov-Smirnov statistics. *Prerequisite: Math. 181B or equivalent or consent of instructor.*

288. Seminar in Probability and Statistics (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

289A-B-C. Topics in Probability and Statistics (4-4-4)
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 adviser.

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)

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: none.*

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.*

297A-B-C. Topics in Topology (4-4-4)
In recent years, topics have included generalized cohomology theory, spectral sequences, K-theory, homotopy theory. May be repeated for credit with consent of adviser. *Prerequisite: consent of instructor.* (F,W,S)

298. Seminar in Topology (1 to 4)
Prerequisite: consent of instructor. (S/U grades permitted.)

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.)

400. Computing Technology for Mathematicians (2)
Preparation for making effective use of computer technology in research and teaching of mathematics. UNIX basics, document preparation using TeX, Internet resources, HTML, computer technology in teaching. *Prerequisite: graduate status.*

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 adviser.* (S/U grades only.)